Semiannual water column monitoring report

February - July 2000

Massachusetts Water Resources Authority

Environmental Quality Department
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SEMIANNUAL WATER COLUMN MONITORING REPORT

February – July 2000

Submitted to

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EXECUTIVE SUMMARY

The Massachusetts Water Resources Authority (MWRA) has collected water quality data in Massachusetts and Cape Cod Bays for the Harbor and Outfall Monitoring (HOM) Program since 1992. This monitoring is in support of the HOM Program mission to assess the potential environmental effects of the relocation of effluent discharge from Boston Harbor to Massachusetts Bay. The data are being collected to establish baseline water quality conditions and ultimately to provide the means to detect significant departure from that baseline. The surveys have been designed to evaluate water quality on both a high-frequency basis for a limited area in the vicinity of the outfall site (nearfield) and a low-frequency basis over an extended area throughout Boston Harbor, Massachusetts Bay, and Cape Cod Bay (farfield). This semi-annual report summarizes water column monitoring results for the nine surveys conducted from February through July 2000.

The winter to spring transition in Massachusetts and Cape Cod Bays is characterized by a typical series of physical, biological, and chemical events: seasonal stratification, the winter/spring phytoplankton bloom, and nutrient depletion. This was generally the case in 2000. There was a major winter/spring bloom of *Phaeocystis pouchetii* in March/April that was coincident with very high chlorophyll concentrations and the surface waters were depleted in nutrients following the bloom from April through July. The onset of seasonal stratification was delayed in the bays in 2000 due to mixing events associated with inclement weather.

From February to March, the water column was well mixed and relatively high concentrations of nutrients were measured. Nearfield surface nutrient concentrations decreased over this time period coincident with increasing chlorophyll concentrations, elevated primary production rates, and the initiation of the *Phaeocystis* bloom. By late February, there was an increase in phytoplankton abundance in Cape Cod Bay and southern Massachusetts Bay with a mixed assemblage dominated by microflagellates and centric diatoms. By March, phytoplankton abundance had begun to increase in the nearfield and the assemblage was dominated centric diatoms and *Phaeocystis pouchetii*, which was the winter/spring bloom species for 2000.

The onset of stratification was observed during the April survey in Boston Harbor and at the deep boundary stations. The development of stratification at these stations was primarily driven by a decrease in surface salinity, as surface and bottom water temperatures remained relatively unchanged. By June, surface water temperatures had increased by ~7°C throughout the bays and a strong density gradient was observed at the offshore and boundary stations. Due to storm events and associated mixing, stratification was still weak at the shallower coastal, Cape Cod Bay, nearfield, and Boston Harbor stations. By July, a strong density gradient and stratified conditions had become established in the nearfield.

The nutrient data for February to July 2000 generally followed the "typical" progress of seasonal events in the Massachusetts and Cape Cod Bays. Maximum nutrient concentrations were observed in early February when the water column was well mixed and biological uptake of nutrients was limited. The winter/spring *Phaeocystis* bloom reduced nutrient concentrations in the surface waters from March to April. Nutrient concentrations remained depleted throughout much of the region through June and July. The harbor signal of elevated nutrient concentrations (especially ammonium) was observed throughout this time period. During the *Phaeocystis* bloom, however, even nutrient concentrations in Boston Harbor decreased substantially.

The most significant event during the February to July 2000 time period was the system-wide bloom of *Phaeocystis pouchetii*. Phytoplankton abundance reached unprecedented levels in April with *Phaeocystis* abundance levels approaching 14 million cells L^{-1}. In correlation with the *Phaeocystis* bloom, the mean chlorophyll concentration for the nearfield for winter/spring was higher than any previous winter/spring

mean obtained during the baseline monitoring period and exceeded the provisional chlorophyll threshold value that had been calculated as two times the baseline mean for 1992 to 1998. The elevated chlorophyll concentrations and phytoplankton abundance were concomitant with high production rates in the nearfield and Boston Harbor. The typical primary production pattern at harbor station F23 is for rates to increase from winter through summer, which is distinct from the winter/spring peaks typically observed in the nearfield. In 2000, this was not the case as peak production at station F23 occurred in April. The earlier occurrence of peak production values in the harbor was due to the system-wide *Phaeocystis* bloom. The bloom of *Phaeocystis pouchetii* was the only bloom of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during February – July, 2000. The dinoflagellate *Alexandrium tamarense* and diatoms of *Pseudo-nitzschia pungens* and *Pseudo-nitzschia* spp. were recorded, but abundance levels were extremely low (tens to hundreds of cells L^{-1}).

Dissolved oxygen concentrations in 2000 were within the range of values observed during previous years and followed the typical trends. In February, DO concentrations were high and consistent across the region. By April, vertical gradients in DO concentration were observed due to the high rates of biological production. Between the April and June surveys, there was a sharp decline in bottom water DO throughout the bays (1-3 mgL^{-1}). The trend of declining bottom water DO concentrations following the establishment of stratification and the cessation of the winter/spring bloom is typical for the bays. The decline observed in 2000 was less than that seen during 1999, which also saw a significant winter/spring bloom. The reason for the difference is likely due to increased mixing caused by April and June storm events and lower respiration rates in 2000. The higher June bottom water DO concentrations in 2000 in comparison to 1999 may be an indication that bottom water DO concentrations this fall may not achieve the very low levels seen the fall of 1999.

Zooplankton abundance generally increased from February through July. Nearfield counts of nearly 300 x 10^3 animals m^{-3} in June were among the highest for the entire 1992-2000 baseline period. The high June abundance observed in the nearfield was due to a very high number of bivalve veligers at station N16 and is indicative of the biological (spawning) and physical (tides and currents) variability associated with meroplankton abundances and distribution in Massachusetts Bay. In general, zooplankton assemblages during the first half of 2000 were comprised of taxa typically present in the bays. In 2000, levels of *Acartia* spp. rebounded from the unusually low values of the previous year, which were possibly due to drought, to more typical levels during the rainy spring and early summer of this year.

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1.0 INTRODUCTION

1.1 Program Overview

The Massachusetts Water Resources Authority (MWRA) has implemented a long-term Harbor and Outfall Monitoring (HOM) Program for Massachusetts and Cape Cod Bays. The objective of the HOM Program is to (1) test for compliance with NPDES permit requirements; (2) test whether the impact of the discharge on the environment is within the bounds projected by the SEIS; and (3) test whether change within the system exceeds the Contingency Plan thresholds. A detailed description of the monitoring and its rationale is provided in the Effluent Outfall Monitoring Plan developed for the baseline period and the post discharge monitoring plan (MWRA, 1997a).

To help establish the present water quality conditions with respect to nutrients, water properties, phytoplankton and zooplankton, and water-column respiration and productivity, the MWRA conducts baseline water quality surveys in Massachusetts and Cape Cod Bays. The surveys have been designed to evaluate water quality on both a high-frequency basis for a limited area (nearfield) and a low-frequency basis for an extended area (farfield). The nearfield stations are located in the vicinity of the outfall site (Figure 1-1) and the farfield stations are located throughout Boston Harbor, Massachusetts Bay, and Cape Cod Bay (Figure 1-2). The stations for the farfield surveys have been further separated into regional groupings according to geographic location to simplify regional data comparisons. This semi-annual report summarizes water column monitoring results for the nine surveys conducted from February through July 2000 (Table 1-1).

Table 1-1. Water Quality Surveys for WF001-WN009 February to July 2000

Survey #	Type of Survey	Survey Dates
WF001	Nearfield/Farfield	February 2 – 5
WF002	Nearfield/Farfield	February 23 – 27
WN003	Nearfield	March 14
WF004	Nearfield/Farfield	March 30 – April 7
WN005	Nearfield	May 1
WN006	Nearfield	May 17
WF007	Nearfield/Farfield	June 8 – 13
WN008	Nearfield	July 6
WN009	Nearfield	July 19

Initial data summaries, along with specific field information, are available in individual survey reports submitted immediately following each survey. In addition, nutrient data reports (including calibration information, sensor and water chemistry data), plankton data reports, and productivity and respiration data reports are each submitted five times annually. Raw data summarized within this or any of the other reports are available from MWRA in hard copy and electronic formats.

1.2 Organization of the Semi-Annual Report

The scope of the semi-annual report is focused primarily towards providing an initial compilation of the water column data collected during the reporting period. Secondarily, integrated physical and biological results are discussed for key water column events and potential areas for expanded discussion in the annual water column report are recommended. The report first provides a summary of the survey and laboratory methods (Section 2). The bulk of the report, as discussed in further detail below, presents results of water column data from the first nine surveys of 2000 (Sections 3-5). Finally, the major findings of the semi-annual period are summarized in Section 6.

Section 3 data are provided in data summary tables. The summary tables include the major numeric results of water column surveys in the semi-annual period by survey. A description of data selection, integration information, and summary statistics are included with that section.

Sections 4 (Results of Water Column Measurements) and 5 (Productivity, Respiration, and Plankton Results) include preliminary interpretation of the data with selected graphic representations of the horizontal and vertical distribution of water column parameters in both the farfield and nearfield. The horizontal distribution of physical parameters is presented through regional contour plots. The vertical distribution of water column parameters is presented using time-series plots of averaged surface and bottom water column parameters and along vertical transects in the survey area (Figure 1-3). The time-series plots utilize average values of the surface water sample (the "A" depth, as described in Section 3), and the bottom water collection depth (the "E" depth). Examining data trends along four farfield transects (Boston-Nearfield, Cohassett, Marshfield and Nearfield-Marshfield), and one nearfield transect, allows three-dimensional analysis of water column conditions during each survey. One offshore transect (Boundary) enables analysis of results in the outer most boundary of the survey area during farfield surveys.

Results of water column physical, nutrient, chlorophyll, and dissolved oxygen data are provided in Section 4. Survey results were organized according to the physical characteristics of the water column during the semi-annual period. The timing of water column vertical stratification, and the physical and biological status of the water column during stratification, significantly effects the temporal response of the water quality parameters, which provide a major focus for assessing effects of the outfall. This report describes the horizontal and vertical characterization of the water column during pre-stratification stage (WF001 – WF004), and then further delineated processes occurring during the early stratification stage (WN005 – WN009). Time-series data are commonly provided for the entire semi-annual period for clarity and context of the data presentation.

Productivity, respiration, and plankton measurements, along with corresponding discussion of chlorophyll and dissolved oxygen results, are provided in Section 5. Discussion of the biological processes and trends during the semi-annual period is included in this section. A summary of the major water column events and unusual features of the semi-annual period is presented in Section 6. References are provided in Section 7.

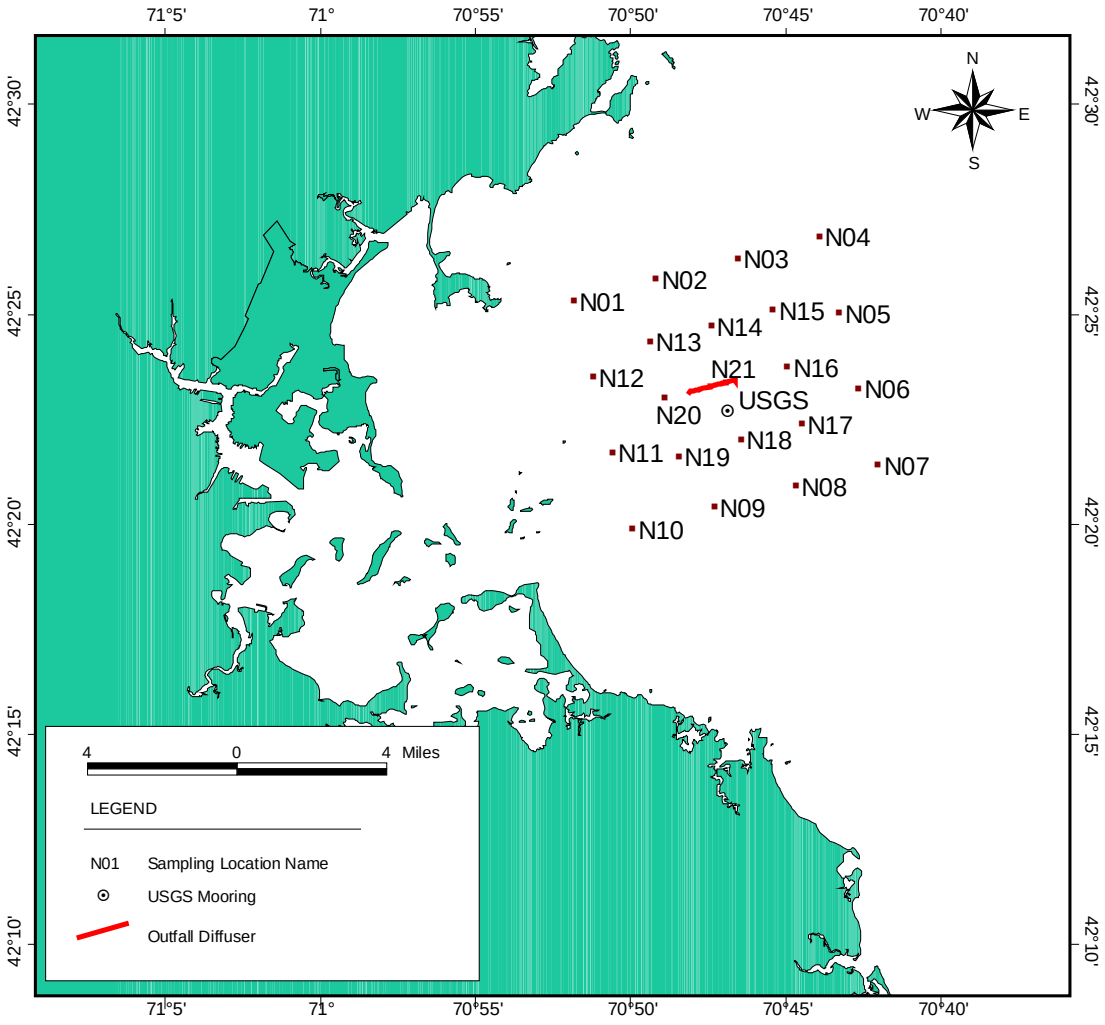


Figure 1-1. Locations of MWRA Offshore Outfall, Nearfield Stations and USGS Mooring

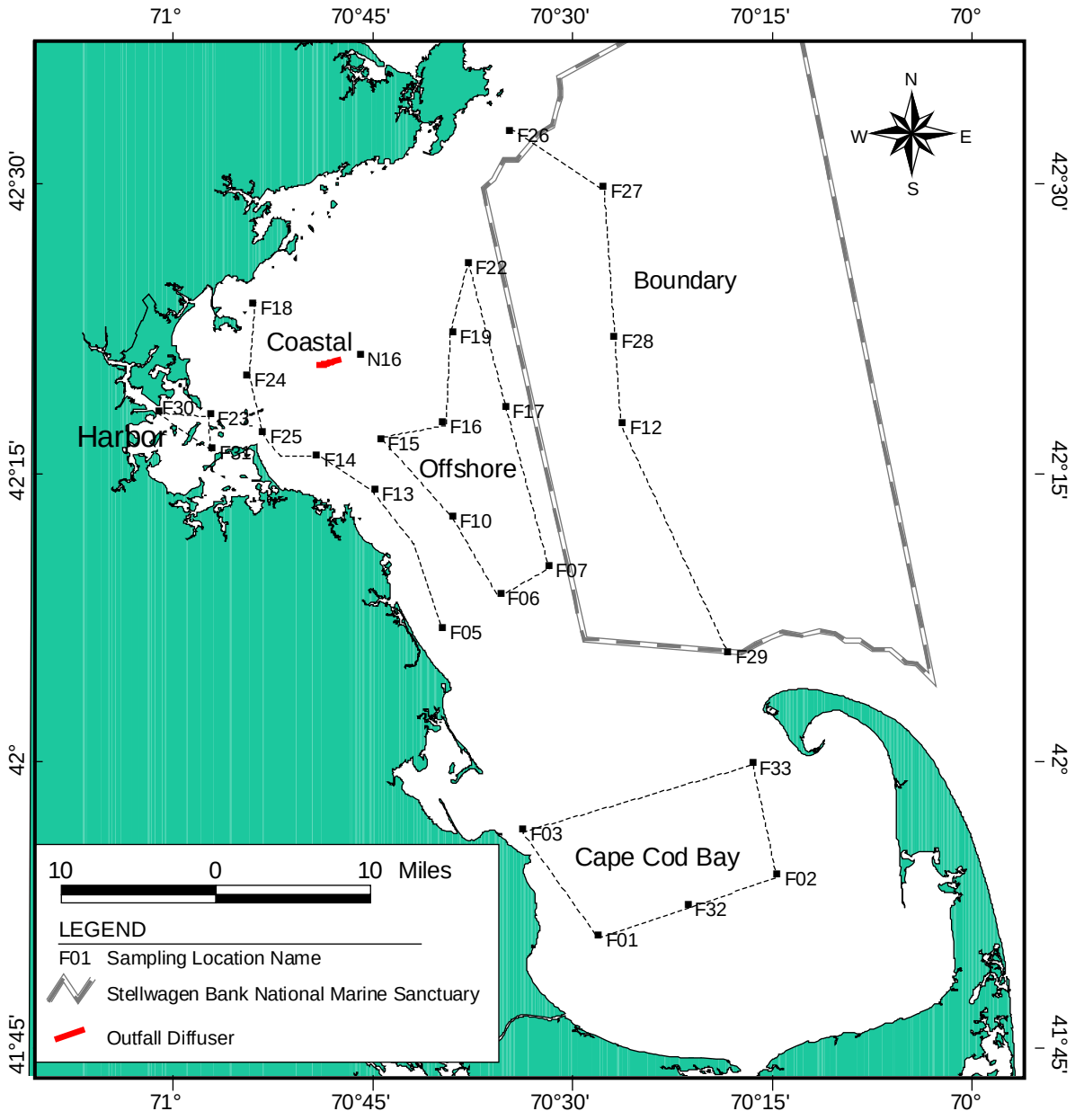


Figure 1-2. Locations of Farfield Stations and Regional Station Groupings

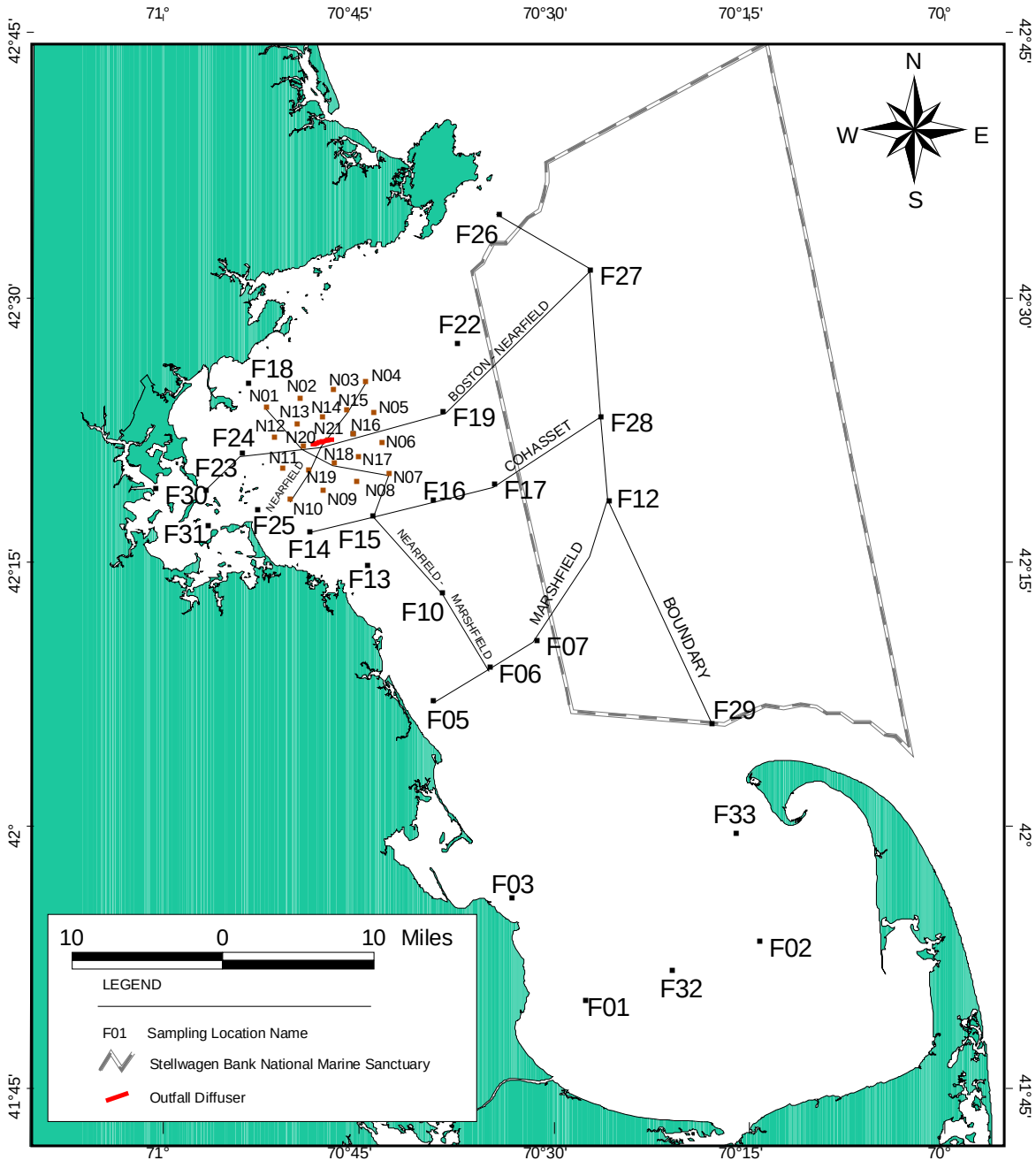


Figure 1-3. Locations of Stations and Selected Transects

2.0 METHODS

This section describes general methods of data collection and sampling for the first nine water column monitoring surveys of 2000. Section 2.1 describes data collection methods, including survey dates, sampling platforms, and analyses performed. Section 2.2 describes the sampling schema undertaken, and Section 2.3 details specific operations for the first 2000 semi-annual period. Specific details of field sampling and analytical procedures, laboratory sample processing and analysis, sample handling and custody, calibration and preventative maintenance, documentation, data evaluation, and data quality procedures are discussed in the Water Quality Monitoring CW/QAPP (Albro *et al*., 1998). Details on productivity sampling procedures and analytical methods are also available in Appendix A.

2.1 Data Collection

The farfield and nearfield water quality surveys for 2000 represent a continuation of the baseline water quality monitoring conducted from 1992 – 1999. The monitoring program has been improved over the years as more data have been collected and evaluated. In 1998, two Cape Cod Bay stations (F32 and F33) were added to better capture the winter/spring variability in zooplankton abundance and species in these Right whale feeding grounds. During the first three farfield surveys of 2000, these two stations were again sampled for zooplankton and hydrographic (CTD) properties. For the 2000 monitoring, a decision was made to collect more data at stations 'upstream' of the nearfield area (stations F22 and F26). Additional nutrient parameters were measured at these stations starting in February (WF001) and during the April survey (WF004) phytoplankton and zooplankton samples were also added to the list of parameters measured at these stations to better define biological conditions at the northeastern boundary of Massachusetts Bay. These additional parameters continue to be measured at stations F22 and F26 during each farfield survey.

Water quality data for this report were collected from the sampling platforms *R/V Aquamonitor* and *F/V Isabel S.* Continuous vertical profiles of the water column and discrete water samples were collected using a CTD/Go-Flo Bottle Rosette system. This system includes a deck unit to control the system, display *in situ* data, and store the data, and an underwater unit comprised of several environmental sensors, including conductivity, temperature, depth, dissolved oxygen, transmissometry, irradiance, and fluorescence. These measurements were obtained at each station by deploying the CTD; in general, one cast was made at each station. Water column profile data were collected during the downcast, and water samples were collected during the upcast by closing the Go-Flo bottles at selected depths, as discussed below.

Water samples were collected at five depths at each station, except at stations F30, F31, F32, and F33. Stations F30 and F31 are shallow and require only three depths while only zooplankton samples are collected at F32 and F33. These depths were selected during CTD deployment based on positions relative to the pycnocline or subsurface chlorophyll maximum. The bottom depth (within 5 meters of the sea floor) and the surface depth (within 3 meters of the water surface) of each cast remained constant and the mid-bottom, middle and mid-surface depths were selected to represent any variability in the water column. In general, the selected middle depth corresponded with the chlorophyll maximum and or pycnocline. When the chlorophyll maximum occurred significantly below or above the middle depth, the mid-bottom or mid-surface sampling event was substituted with the mid-depth sampling event and the "mid-depth" sample was collected within the maximum. In essence, the "mid-depth" sample in these instances was not collected from the middle depth, but shallower or deeper in the water column in order to capture the chlorophyll maximum layer. These nomenclature semantics result from a combination of field logistics and scientific relevance. In the field, the switching of the "mid-depth" sample with the mid-surface or mid-bottom was transparent to

everyone except the NAVSAM operator who observed the subsurface chlorophyll structure and marked the events. The samples were processed in a consistent manner and a more comprehensive set of analyses were conducted for the surface, mid-depth/chlorophyll maximum, and bottom samples.

Samples from each depth at each station were collected by subsampling from the Go-Flo bottles into the appropriate sample container. Analyses performed on the water samples are summarized in Table 2-1. Samples for dissolved inorganic nutrients (DIN), dissolved organic carbon (DOC), total dissolved nitrogen (TDN) and phosphorus (TDP), particulate organic carbon (POC) and nitrogen (PON), biogenic silica, particulate phosphorus (PP), chlorophyll *a* and phaeopigments, total suspended solids (TSS), urea, and phytoplankton (screened and rapid assessment) were filtered and preserved immediately after obtaining water from the appropriate Go-Flo bottles. Whole water phytoplankton samples (unfiltered) were obtained directly from the Go-Flo bottles and immediately preserved. Zooplankton samples were obtained by deploying a zooplankton net overboard and making an oblique tow of the upper two-thirds of the water column but with a maximum tow depth of 30 meters. Productivity samples were collected from the Go-Flo bottles, stored on ice and transferred to University of Rhode Island (URI) employees. Incubation was started no more that six hours after initial water collection at URI's laboratory. Respiration samples were collected from the Go-Flo bottles at four stations (F19, F23, N04, and N18). Incubations of the dark bottles were started within 30 minutes of sample collection. The dark bottle samples were maintained at a temperature within 2°C of the collection temperature for five to seven days until analysis.

2.2 Sampling Schema

A synopsis of the sampling schema for the analyses described above is outlined in Tables 2-1, 2-2, and 2-3. Station designations were assigned according to the type of analyses performed at that station (see Table 2-1). Productivity and respiration analyses were also conducted at certain stations and represented by the letters P and R, respectively. Table 2-1 lists the different analyses performed at each station. Tables 2-2 (nearfield stations) and 2-3 (farfield stations) provide the station name and type, and show the analyses performed at each depth. Station N16 is considered both a nearfield station (where it is designated as type A) and a farfield station (where it is designated a type D). Stations F32 and F33 are occupied during the first three farfield surveys of each year and collect zooplankton samples and hydrocast data only (designated as type Z). During 2000, a decision was made to collect more data at stations F22 and F26. Phytoplankton, zooplankton and additional nutrient samples were taken at these stations starting in 2000. Stations F22 and F26 were sampled as type A stations (additional nutrients) during the first two farfield surveys (WF001 and WF002) and as type D stations (addition of plankton samples) during the last two farfield surveys of this time period (WF004 and WF007).

Table 2-1. Station Types and Numbers (Five Depths Collected Unless Otherwise Noted)

Station Type	A	D	E	F	G[1]	P	R[5]	Z
Number of Stations	5	10[4]	24	3	2	3	1	2
Analysis Type								
Dissolved inorganic nutrients (NH_4, NO_3, NO_2, PO_4, and SiO_4)	●	●	●	●	●	●		
Other nutrients (DOC, TDN, TDP, PC, PN, PP, Biogenic Si)[1]	●	●			●	●		
Chlorophyll [1]	●	●			●	●		
Total suspended solids [1]	●	●			●	●		
Dissolved oxygen	●	●		●	●	●		
Phytoplankton, urea [2]		●			●	●		
Zooplankton[3]		●			●	●		●
Respiration [1]						●	●	
Productivity, DIN						●		

[1]Samples collected at three depths (bottom, mid-depth, and surface)
[2]Samples collected at two depths (mid-depth and surface)
[3]Vertical tow samples collected
[4]Stations F22 and F26 accounted as type D stations in this table
[5]Respiration samples collected at type F station F19

2.3 Operations Summary

Field operations for water column sampling and analysis during the first semi-annual period were conducted as described above. Deviations from the CW/QAPP for surveys WF002, WN003, WF004, WN005, WF007, WN008, and WN009 had no effect on the data or data interpretation. The principal deviations for surveys WF001 and WN006 are described below. For additional information about a specific survey, the individual survey reports may be consulted.

During survey WF001, productivity samples were not collected at station F23 during the first visit to that site on the nearfield portion of the survey (February 3). Productivity samples are normally collected at stations F23, N04, and N18 on the same day, but in this instance, productivity samples at station F23 were collected the following morning (February 4) at 7:15 a.m.

During the nearfield survey in mid-May (WN006), the respiration samples were allowed to rise to room temperature over a 12-hour period. The temperature was corrected upon discovery, but the data are qualified as suspect and not included in this report.

Table 2-2. Nearfield Water Column Sampling Plan (3 Pages)

Nearfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Rapid Analysis Phytoplankton	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	UR	RE	AP	IC
			Volume (L)			1	0.1	0.1	1	0.6	0.3	0.5	1	1	4	1	4	1	0.1	1	1	1
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N01	30	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N02	40	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N03	44	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	15.5	2	1	1	1	2	2	2	1	2							6	1	1
			2_Mid-Bottom	4.5	1	1						1		1							1	1
N04	50	D+	3_Mid-Depth	22.1	2	2	1	1	2	2	2	2	2			1	1		1	6	1	1
		R+	4_Mid-Surface	4.5	1	1						1		1							1	1
		P	5_Surface	20.6	2	1	1	1	2	2	2	1	2			1	1		1	6	1	1
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N05	55	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N06	52	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	10.5	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
N07	52	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	10.5	2	1	1	1	2	2	2	1	2	3								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N08	35	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																

Nearfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Rapid Analysis Phytoplankton	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	UR	RE	AP	IC
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N09	32	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N10	25	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N11	32	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N12	26	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N13	32	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N14	34	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N15	42	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N16	40	A	3_Mid-Depth	10.2	2	2	2	2	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N17	36	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																

Nearfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Rapid Analysis Phytoplankton	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	UR	RE	AP	IC
			5_Surface	1	1	1																
			1_Bottom	15.5	2	1	1	1	2	2	2	1	2							6	1	1
		D+	2_Mid-Bottom	4.5	1	1						1		1							1	1
N18	30	R+	3_Mid-Depth	26.1	3	1	1	1	2	2	2	2	2		1	1	1		1	6	1	2
		P	4_Mid-Surface	4.5	1	1						1		1							1	1
			5_Surface	20.6	2	1	1	1	2	2	2	1	2			1	1		1	6	1	1
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N19	24	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N20	32	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N21	34	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			Totals			111	22	22	42	42	42	42	42	33	1	4	4	2	4	36	10	11
Blanks A									1	1	1	1	1									

Table 2-3. Farfield Water Column Sampling Plan (3 Pages)

Farfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	UR	RE	AP	IC
			Volume (L)			1	0.1	0.1	1	0.3	0.3	0.5	1	1	0	1	4	1	0.1	1	1	1
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
F01	27	D	3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
F02	33	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F03	17	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F05	18	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
F06	35	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F07	54	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F10	30	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	4	1	1								1								
			2_Mid-Bottom	2	1	1								1								
F12	90	F	3_Mid-Depth	2	1	1								1								
			4_Mid-Surface	2	1	1								1								
			5_Surface	4	1	1								1	1							
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
F13	25	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								

Farfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	UR	RE	AP	IC
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F14	20	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F15	39	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F16	60	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F17	78	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F18	24	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	7	2	1														6		
			2_Mid-Bottom	2	1	1								1								
F19	81	F	3_Mid-Depth	7	2	1														6		
		+R	4_Mid-Surface	2	1	1								1								
			5_Surface	7	2	1									1					6		
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
F22	80	D	3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	18	3	1	1	1	2	2	2	1	2							6	1	1
		D	2_Mid-Bottom	8.5	1	1						1		1							1	2
F23	25	+R	3_Mid-Depth	24	3	1	1	1	2	2	2	2	2			1	1		1	6	1	1
		+P	4_Mid-Surface	7.5	1	1						1		1							1	1
			5_Surface	23	3	1	1	1	2	2	2	1	2		1	1	1		1	6	1	1
			6_Net Tow															1				
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
F24	20	D	3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	9.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								

Farfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	UR	RE	AP	IC
F25	15	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
F26	56	D	3_Mid-Depth	15	2	1	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
F27	108	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F28	33	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	2	1	1								1								
			2_Mid-Bottom	2	1	1								1								
F29	66	F	3_Mid-Depth	2	1	1								1								
			4_Mid-Surface	2	1	1								1								
			5_Surface	2	1	1								1	1							
			1_Bottom	9.9	2	1	1	1	2	2	2	1	2	3								
			3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
F30	15	G	5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	9.9	2	1	1	1	2	2	2	1	2	3								
			3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
F31	15	G	5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
F32	30	Z	5_Surface												1							
			6_Net Tow															1				
F33	30	Z	5_Surface												1							
			6_Net Tow															1				
			1_Bottom	8.1	2	1	2	2	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N16	40	D	3_Mid-Depth	15	2	2	2	2	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			6_Net Tow															1				
					otals	132	41	41	78	78	78	74	78	96	28	26	26	15	26	36	5	6
			Blanks B						1	1	1	1	1									
			Blanks C						1	1	1	1	1									
			Blanks D						1	1	1	1	1									

3.0 DATA SUMMARY PRESENTATION

Data from each survey were compiled from the final HOM Program 2000 database and organized to facilitate regional comparisons between surveys, and to allow a quick evaluation of results for evaluating monitoring thresholds (Table 3-1 Method Detection Limits, Survey Data Tables 3-2 through 3-10). Each table provides summary data from one survey. A discussion of which parameters were selected, how the data were grouped and integrated, and the assumptions behind the calculation of statistical values (average, minimum, and maximum), is provided below. Individual data summarized in this report are available from MWRA either in hard copy or electronic format.

The spatial pattern of data summary follows the sample design over major geographic areas of interest in Massachusetts Bay, Cape Cod Bay, and Boston Harbor (Section 3.1). Compilation of data both horizontally by region and vertically over the entire water column was conducted to provide an efficient way of assessing the status of the regions during a particular survey. Maximum and minimum values are provided because of the need to assess extremes of pre-outfall conditions relative to criteria being developed for contingency planning purposes (MWRA, 1997b).

Regional compilations of nutrient and biological water column data were conducted first by averaging individual laboratory replicates, followed by field duplicates, and then by station visit within a survey. Prior to regional compilation of the sensor data, the results were averaged by station visit. Significant figures for average values were selected based on precision of the specific data set. Detailed considerations for individual data sets are provided in the sections below.

3.1 Defined Geographic Areas

The primary partitioning of data is between the nearfield and farfield stations (Figures 1-1 and 1-2). Farfield data were additionally segmented into five geographic areas: stations in Boston Harbor (F23, F30, and F31), coastal stations (F05, F13, F14, F18, F24, F25), offshore stations (F06, F07, F10, F15, F16, F17, F19, and F22), boundary region stations (F12, F26, F27, F28, F29), and Cape Cod Bay stations (F01, F02, and F03; and F32 and F33 as appropriate). These regions are shown in Figure 1-2.

The data summary tables include data derived from all of the station data collected in each region. Average, maximum, and minimum values are reported from the cumulative horizontal and vertical dataset as described for each data type below.

3.2 Sensor Data

Six CTD profile parameters provided in the data summary tables include temperature, salinity, density (σ_t), fluorescence (chlorophyll a), transmissivity, and dissolved oxygen (DO) concentration. Statistical parameters (maximum, minimum, and average) were calculated from the sensor readings collected at five depths through the water column (defined as A-E). These depths were sampled on the upcast of the hydrographic profile. The five depth values, rather than the entire set of profile data, were selected to reduce the statistical weighting of deep-water data at the offshore and boundary stations. Generally, the samples were collected in an even depth-distributed pattern. The mid-depth sample (C) was typically located at the subsurface fluorescence (chlorophyll) peak in the water column, depending on the relative depth of the chlorophyll maximum. Details of the collection, calibration, and processing of CTD data are available in the Water Column Monitoring CW/QAPP (Albro *et al*., 1998), and are summarized in Section 2.

Following standard oceanographic practice, patterns of variability in water density are described using the derived parameter sigma-t (σ_t), which is calculated by subtracting 1,000 kg/m^3 from the recorded density. During this semi-annual period, density varied from 1020.1 to 1026.4, meaning σ_t varied from 20.1 to 26.4.

Fluorescence data were calibrated using concomitant extracted chlorophyll *a* data from discrete water samples collected at a subset of the stations (see CW/QAPP or Tables 2-1, 2-2, 2-3). The calibrated fluorescence sensor values were used for all discussions of chlorophyll in this report. The concentrations of phaeopigments are included in the summary data tables as part of the nutrient parameters.

In addition to DO concentration, the derived percent saturation was also provided. Percent saturation was calculated prior to averaging station visits from the potential saturation value of the water (a function of the physical properties of the water) and the calibrated DO concentration (see CW/QAPP).

Finally, the derived beam attenuation coefficient from the transmissometer ("transmittance") was provided on the summary tables. Beam attenuation is calculated from the natural logarithm of the ratio of light transmission relative to the initial light incidence, over the transmissometer path length, and is provided in units of m^{-1}.

3.3 Nutrients

Analytical results for dissolved and particulate nutrient concentrations were extracted from the HOM database, and include: ammonia (NH_4), nitrite (NO_2), nitrate + nitrite (NO_3+NO_2), phosphate (PO_4), silicate (SiO_4), biogenic silica (BSI), dissolved and particulate organic carbon (DOC and POC), total dissolved and particulate organic nitrogen (TDN and PON), total dissolved and particulate phosphorous (TDP and PP), and urea. Total suspended solids (TSS) data are provided as a baseline for total particulate matter in the water column. Dissolved inorganic nutrients (NH_4, NO_2, NO_3+NO_2, PO_4, and SiO_4) were measured from water samples collected from each of the five (A-E) depths during CTD casts. The dissolved organic and particulate constituents were measured from water samples collected from the surface (A), mid-depth (C), and bottom (E) sampling depths (see Tables 2-1, 2-2, and 2-3 for specific sampling depths and stations).

3.4 Biological Water Column Parameters

Four productivity parameters have been presented in the data summary tables. Areal production, which is determined by integrating the measured productivity over the photic zone, and chlorophyll-specific areal production is included for the productivity stations (F23 representing the Harbor, and N04 and N18, representing the nearfield). Because areal production is already depth-integrated, averages were calculated only among productivity stations for the two regions sampled. The derived parameters α ($gC[gChla]^{-1}h^{-1}[\mu Em^{-2}s^{-1}]^{-1}$) and Pmax ($gC[gChla]^{-1}h^{-1}$) are also included. The productivity parameters are discussed in detail in Appendix A.

Respiration rates were averaged over the respiration stations (the same Harbor and nearfield stations as productivity, and additionally one offshore station [F19]), and over the three water column depths sampled (surface, mid- and bottom). The respiration samples were collected concurrently with the productivity samples. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (Albro *et al*., 1998).

3.5 Plankton

Plankton results were extracted from the HOM database and include whole water phytoplankton, screened phytoplankton, and zooplankton. Phytoplankton samples were collected for whole-water and screened measurements during the water column CTD casts at the surface (A) and mid-depth (C) sampling events. As discussed in Section 2.1, when a subsurface chlorophyll maximum is observed, the mid-depth sampling event is associated with this layer. The screened phytoplankton samples were filtered through 20-µm Nitrex mesh to retain and concentrate larger dinoflagellate species. Zooplankton samples were collected by oblique tows using a 102-µm mesh at all plankton stations. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (Albro *et al*., 1998).

Final plankton values were derived from each station by first averaging analytical replicates, then averaging station visits. Regional results were summarized for total phytoplankton, total centric diatoms, nuisance algae (*Alexandrium tamarense, Phaeocystis pouchetii,* and *Pseudo-nitzschia pungens*), and total zooplankton (Tables 3-2 through 3-10).

Results for total phytoplankton and centric diatoms reported in Tables 3-1 through 3-10 are restricted to whole water surface samples. Results of the nuisance species *Phaeocystis pouchetii* and *Pseudo-nitzschia pungens* include the maximum of both whole water and screened analyses, at both the surface and mid-depth. Although the size and shape of both taxa might allow them to pass through the Nitex screen, both have colonial forms that in low densities might be overlooked in the whole-water samples. For *Alexandrium tamarense*, only the screened samples were reported.

3.6 Additional Data

Two additional data sources were utilized during interpretation of HOM Program semi-annual water column data. Temperature and chlorophyll *a* satellite images collected near survey dates were preliminarily interpreted for evidence of surface water events, including intrusions of surface water masses from the Gulf of Maine and upwelling (Appendix I). U.S. Geological Service continuous temperature and salinity data were collected from a mooring located between nearfield stations N21 and N18 (Figure 1-1). Hourly temperature and salinity data from the mid-depth (~20 m below surface) and near-bottom (1 m above bottom) are plotted in Figure 3-1. Chlorophyll *a* data (as measured by *in situ* fluorescence) from the MWRA Wetlab sensor mounted at mid-depth (~12 m below surface) on the nearfield USGS mooring are plotted in Figure 3-2.

3.7 Data Revisions

Two sets of data were revised based on analytical and sensor issues that were discovered in early 2001 – chlorophyll and irradiance. The data have been corrected and the new data are presented herein and have been used for all applicable calculations included in this report (i.e. areal production and chlorophyll-specific production).

A quality assurance review found analytical errors in the chlorophyll measurement method used by the MWRA monitoring program during 1998-2000. In the fall of 2000, extracted chlorophyll and draft calibrated fluorescence data exhibited unusually high values relative to other fall data collected under HOM. These high values precipitated a major review of HOM3 chlorophyll and fluorescence data the findings of which are summarized in Hunt 2001. In our evaluation of the fluorescence and bottle chlorophyll data, the project team identified two major technical issues requiring action: correction for chlorophyll standard purity (all HOM3 data) and degradation of the chlorophyll standard (limited number of surveys). Each issue had led to an upward bias in the extracted chlorophyll data and calibrated fluorescence.

The irradiance data was corrected based on problems with the MWRA Deer Island light sensor. The problem was discovered when the sensor was replaced on April 20, 2001 and the old unit subsequently post-calibrated. The new calibration values were different from the initial values (used throughout HOM3) and were the result of damage to the unit during installation (10/96). The revised Deer Island surface irradiance data were used to recalculate the productivity data presented in this report.

Table 3-1. Method Detection Limits

Analysis	MDL
Dissolved ammonia (NH_4)	0.02 µM
Dissolved inorganic nitrate (NO_3)	0.01 µM
Dissolved inorganic nitrite (NO_2)	0.01 µM
Dissolved inorganic phosphorus (PO_4)	0.01 µM
Dissolved inorganic silicate (SIO_4)	0.02 µM
Dissolved organic carbon (DOC)	20 µM
Total dissolved nitrogen (TDN)	1.43 µM
Total dissolved phosphorus (TDP)	0.04 µM
Particulate carbon (POC)	5.27 µM
Particulate nitrogen (PON)	0.75 µM
Particulate phosphorus (PARTP)	0.04 µM
Biogenic silica (BIOSI)	0.32 µM
Urea	0.2 µM
Chlorophyll *a* and phaeophytin	0.036 µg L^{-1}
Total suspended solids (TSS)	0.1 mg L^{-1}

Table 3-2. Combined Farfield/Nearfield Survey WF001 (Feb 00) Data Summary

		Farfield								
Region		**Boundary**			**Cape Cod Bay**			**Coastal**		
Parameter	**Unit**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
In Situ										
Temperature	°C	2.98	5.48	4.01	0.21	2.52	1.55	0.51	2.99	1.75
Salinity	PSU	32.8	33.4	33.0	32.2	32.6	32.5	32.2	32.8	32.5
Sigma _T		26.1	26.3	26.2	25.9	26.0	26.0	25.8	26.1	26.0
Beam Attenuation	m^{-1}	0.57	0.73	0.65	0.80	1.45	1.00	0.67	1.27	0.84
DO Concentration	mgL^{-1}	9.54	10.38	9.92	11.14	14.72	12.25	10.81	13.14	11.74
DO Saturation	PCT	90.8	98.0	94.1	101.2	126.4	109.3	99.7	113.7	105.4
Fluorescence	μgL^{-1}	0.09	5.76	3.85	0.19	50.23	8.49	0.26	25.57	4.99
Chlorophyll a	μgL^{-1}	0.56	1.13	0.82	0.65	3.89	2.04	0.01	1.77	0.91
Phaeopigment	μgL^{-1}	0.18	0.31	0.23	0.22	0.65	0.40	0.08	0.73	0.24
Nutrients										
NH4	µM	0.26	1.08	0.55	0.44	3.45	1.40	0.50	7.71	3.28
NO2	µM	0.09	0.17	0.13	0.08	0.22	0.12	0.07	0.27	0.14
NO2+NO3	µM	8.91	11.64	10.23	5.64	7.80	6.87	7.11	8.41	7.67
PO4	µM	0.96	1.12	1.03	0.73	1.01	0.90	0.92	1.09	1.02
SIO4	µM	6.90	10.05	8.69	2.84	4.99	4.34	5.19	6.76	5.86
BIOSI	µM	1.00	1.90	1.37	0.26	3.60	1.24	0.90	1.70	1.20
DOC	µM	151.3	382.3	220.2	121.1	233.9	183.8	131.4	258.0	176.5
PARTP	µM	0.05	0.09	0.07	0.13	0.23	0.17	0.11	0.16	0.13
POC	µM	7.17	9.50	8.16	11.70	25.30	15.85	8.92	12.70	10.76
PON	µM	1.22	1.64	1.40	1.75	3.56	2.46	1.40	2.31	1.89
TDN	µM	18.9	22.9	20.9	14.1	21.1	17.7	18.0	25.1	21.6
TDP	µM	1.18	1.30	1.24	0.96	1.15	1.05	1.04	1.49	1.29
TSS	mgL^{-1}	2.63	5.79	4.40	2.94	8.62	5.75	3.17	7.00	5.64
Urea	µM	0.39	0.52	0.46	0.12	4.62	1.28	0.06	1.32	0.61
Productivity										
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$									
Pmax	$mgCm^{-3}h^{-1}$									
Areal Production	$mgCm^{-2}d^{-1}$									
Chlorophyll Specific Areal Production	$mgC(mg\ Chla)^{-1}m^{-2}d^{-1}$									
Respiration	μMO_2h^{-1}									
Plankton										
Total Phytoplankton	10^6Cells L^{-1}	0.260	0.261		0.361	0.588		0.242	0.709	
Centric diatoms	10^6Cells L^{-1}	0.019	0.030		0.046	0.150		0.038	0.090	
Alexandrium spp.	Cells L^{-1}	ND	ND		ND	ND		1.50	1.50	
Phaeocystis pouchetiii	10^6Cells L^{-1}	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND		ND	ND		0.001	0.001	

Total Zooplankton	Individuals m^{-3}	5263	5263		10098	16523		924	11135

Table 3-2. Combined Farfield/Nearfield Survey WF001 (Feb 00) Data Summary (continued)

		Farfield								
Region		**Harbor**			**Offshore**			**Nearfield**		
Parameter	**Unit**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
In Situ										
Temperature	°C	0.38	1.28	0.83	2.00	4.04	3.19	0.57	3.71	3.21
Salinity	PSU	31.5	32.3	32.0	32.5	32.9	32.7	32.2	32.8	32.8
Sigma _T		25.3	25.9	25.7	25.9	26.1	26.0	25.8	26.1	26.1
Beam Attenuation	m^{-1}	0.92	1.73	1.29	0.66	1.24	0.81	0.64	1.13	0.83
DO Concentration	mgL^{-1}	10.43	13.05	12.17	9.55	11.82	10.57	9.58	12.68	10.38
DO Saturation	PCT	92.0	112.2	105.9	90.1	106.6	98.2	90.2	110.0	96.3
Fluorescence	μgL^{-1}	3.57	4.53	3.97	0.16	5.37	1.68	0.16	5.58	2.04
Chlorophyll a	μgL^{-1}	0.01	0.91	0.62	0.73	1.31	1.16	0.60	1.90	1.25
Phaeopigment	μgL^{-1}	0.21	0.57	0.32	0.20	0.50	0.29	0.11	0.35	0.24
Nutrients										
NH4	µM	6.46	17.09	12.01	0.34	2.49	0.69	0.04	7.63	0.83
NO2	µM	0.01	0.33	0.22	0.05	0.15	0.09	0.05	0.21	0.11
NO2+NO3	µM	5.62	8.70	7.31	5.88	10.41	7.91	7.00	9.56	8.40
PO4	µM	0.84	1.70	1.19	0.84	1.14	0.96	0.70	1.19	0.97
SIO4	µM	4.76	9.32	6.73	3.80	8.72	5.86	4.79	15.74	6.78
BIOSI	µM	1.20	2.20	1.60	1.70	2.40	1.97	1.10	2.90	1.99
DOC	µM	133.8	417.4	231.7	141.3	433.2	259.8	128.5	448.0	196.3
PARTP	µM	0.14	0.30	0.24	0.08	0.25	0.12	0.07	0.19	0.12
POC	µM	13.70	22.60	17.32	6.32	28.20	15.15	6.73	18.50	11.97
PON	µM	2.31	3.14	2.68	0.93	2.71	2.02	1.17	3.33	1.96
TDN	µM	26.3	61.8	35.4	19.0	39.8	24.8	16.7	31.8	20.4
TDP	µM	1.16	1.57	1.41	0.84	1.35	1.09	0.99	25.44	2.49
TSS	mgL^{-1}	4.40	9.13	6.63	1.92	8.58	4.68	1.55	12.22	5.30
Urea	µM	0.46	0.85	0.64	0.39	3.43	1.91	0.19	0.98	0.45
Productivity										
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.014	0.027	0.021				0.018	0.048	0.032
Pmax	$mgCm^{-3}h^{-1}$	2.10	3.08	2.45				2.25	5.60	3.99
Areal Production	$mgCm^{-2}d^{-1}$	131.7	131.7	131.7				448.3	660.6	554.5
Chlorophyll Specific Areal Production	$mgC(mg\ Chla)^{-1}m^{-2}d^{-1}$	152.4	152.4	152.4				320.2	451.9	386.1
Respiration	μMO_2h^{-1}	0.069	0.097	0.082	0.011	0.060	0.030	0.022	0.087	0.053
Plankton										
Total Phytoplankton	10^6Cells L^{-1}	0.243	0.745		0.755	0.809		0.298	0.675	
Centric diatoms	10^6Cells L^{-1}	0.060	0.105		0.106	0.133		0.059	0.116	
Alexandrium spp.	Cells L^{-1}	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchetii	10^6Cells L^{-1}	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND		ND	ND		ND	ND	
Total Zooplankton	Individuals m^{-3}	1980	5556		12718	12718		7590	16521	

Table 3-3. Combined Farfield/Nearfield Survey WF002 (Feb 00) Data Summary

		Farfield								
Region		**Boundary**			**Cape Cod Bay**			**Coastal**		
Parameter	**Unit**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
In Situ										
Temperature	°C	3.03	4.96	3.73	1.69	2.88	2.05	2.23	2.76	2.53
Salinity	PSU	32.6	33.4	33.0	32.3	32.5	32.4	32.0	32.8	32.4
Sigma _T		26.0	26.4	26.2	25.8	26.0	25.9	25.5	26.1	25.8
Beam Attenuation	m^{-1}	0.87	1.97	1.19	1.21	1.99	1.47	0.73	1.70	1.12
DO Concentration	mgL^{-1}	10.13	11.35	10.66	11.22	13.14	12.19	10.64	11.82	11.39
DO Saturation	PCT	97.7	105.1	100.6	101.1	119.2	110.0	97.8	107.2	103.9
Fluorescence	μgL^{-1}	0.03	0.98	0.55	1.67	23.52	8.98	0.23	4.96	2.05
Chlorophyll a	μgL^{-1}	0.67	1.38	1.06	4.87	14.72	9.31	1.15	3.25	1.94
Phaeopigment	μgL^{-1}	0.21	0.38	0.31	0.66	1.36	1.00	0.28	0.56	0.36
Nutrients										
NH4	µM	0.43	1.51	0.80	0.28	1.59	1.06	0.97	8.04	3.46
NO2	µM	0.12	0.22	0.18	0.01	0.12	0.08	0.14	0.29	0.21
NO2+NO3	µM	7.12	12.74	11.06	0.24	4.56	2.67	6.80	10.08	9.15
PO4	µM	0.91	1.32	1.12	0.36	0.79	0.58	0.76	1.28	1.06
SIO4	µM	4.39	9.29	7.72	0.16	2.69	1.59	3.91	7.32	5.98
BIOSI	µM	0.80	2.10	1.52	2.60	4.00	3.28	1.20	1.70	1.38
DOC	µM	146.7	355.3	243.5	161.5	432.7	248.0	174.8	400.5	292.4
PARTP	µM				0.17	0.49	0.36	0.08	0.18	0.13
POC	µM	6.28	10.60	8.20	22.80	55.10	35.92	7.54	16.80	12.93
PON	µM	1.06	1.85	1.37	3.55	7.71	5.53	1.39	3.02	2.33
TDN	µM	20.4	26.8	22.9	10.5	25.9	16.5	20.9	26.5	23.9
TDP	µM	1.20	1.33	1.24	0.62	0.92	0.75	1.14	1.46	1.27
TSS	mgL^{-1}	0.09	1.14	0.52	1.03	1.67	1.31	0.15	1.14	0.70
Urea	µM	0.09	0.19	0.14	0.29	0.70	0.43	0.22	1.65	0.69
Productivity										
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$									
Pmax	$mgCm^{-3}h^{-1}$									
Areal Production	$mgCm^{-2}d^{-1}$									
Chlorophyll Specific Areal Production	$mgC(mg\ Chla)^{-1}m^{-2}d^{-1}$									
Respiration	μMO_2h^{-1}									
Plankton										
Total Phytoplankton	10^6Cells L^{-1}	0.135	0.241		1.155	1.500		0.172	0.824	
Centric diatoms	10^6Cells L^{-1}	0.007	0.010		0.360	0.768		0.014	0.180	
Alexandrium ssp.	Cells L^{-1}	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchetii	10^6Cells L^{-1}	ND	ND		ND	ND		ND	ND	

Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND		ND	ND		ND	ND		
Total Zooplankton	Individuals m^{-3}	7866	7866		7388	29221		11416	16618		

Table 3-3. Combined Farfield/Nearfield Survey WF002 (Feb 00) Data Summary (continued)

		Farfield								
Region		Harbor			Offshore			Nearfield		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	°C	2.64	3.16	2.83	2.35	4.49	3.19	2.73	3.76	3.17
Salinity	PSU	30.7	31.9	31.6	32.3	33.3	32.8	32.0	33.0	32.7
Sigma _T		24.5	25.5	25.2	25.8	26.4	26.1	25.5	26.3	26.0
Beam Attenuation	m^{-1}	0.97	1.76	1.38	0.78	1.55	1.12	0.74	1.55	1.15
DO Concentration	mgL^{-1}	11.07	11.76	11.28	9.70	11.75	10.92	10.25	11.55	10.95
DO Saturation	PCT	100.7	107.6	103.2	93.1	107.3	101.5	96.4	106.7	101.7
Fluorescence	μgL^{-1}	0.30	2.07	1.10	0.04	7.10	2.30	0.05	8.41	2.05
Chlorophyll a	μgL^{-1}	1.44	2.38	1.79	0.86	5.49	2.58	1.02	2.97	1.81
Phaeopigment	μgL^{-1}	0.35	0.75	0.52	0.27	0.71	0.39	0.18	0.63	0.35
Nutrients										
NH4	µM	5.21	47.65	14.98	0.43	4.76	1.20	0.05	7.77	1.65
NO2	µM	0.32	0.90	0.45	0.11	0.22	0.16	0.12	0.32	0.19
NO2+NO3	µM	9.75	12.82	10.91	7.38	12.52	9.90	8.57	11.19	9.59
PO4	µM	1.01	2.21	1.34	0.87	1.26	1.09	0.11	1.24	1.11
SIO4	µM	6.13	13.47	8.70	4.34	10.91	6.80	5.98	8.40	6.86
BIOSI	µM	1.40	2.30	1.80	0.80	1.80	1.42	0.80	2.80	1.48
DOC	µM	211.1	421.0	311.6	181.5	412.1	304.0	157.9	641.2	262.3
PARTP	µM				0.06	0.21	0.14	0.06	0.20	0.12
POC	µM	15.80	53.40	24.80	8.67	18.30	12.58	5.35	21.10	11.99
PON	µM	2.69	7.50	4.04	1.34	3.41	2.27	1.11	3.52	2.21
TDN	µM	24.6	73.0	37.6	17.7	26.8	21.7	18.8	36.7	22.4
TDP	µM	1.22	2.68	1.58	1.05	1.28	1.16	1.14	1.45	1.25
TSS	mgL^{-1}	0.60	2.96	1.52	0.35	1.01	0.59	0.05	1.28	0.51
Urea	µM	0.29	1.55	0.73	0.60	0.80	0.70	0.09	1.78	0.82
Productivity										
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.018	0.049	0.030				0.011	0.085	0.042
Pmax	$mgCm^{-3}h^{-1}$	3.82	6.64	4.69				1.35	10.91	5.38
Areal Production	$mgCm^{-2}d^{-1}$	471.2	471.2	471.2				682.2	701.5	691.9
Chlorophyll Specific Areal Production	$mgC(mg\ Chla)^{-1}m^{-2}d^{-1}$	236.5	236.5	236.5				250.2	354.3	302.3
Respiration	μMO_2h^{-1}				0.005	0.046	0.030	0.027	0.101	0.049
Plankton										
Total Phytoplankton	10^6Cells L^{-1}	0.369	0.715		0.746	1.105		0.125	0.382	
Centric diatoms	10^6Cells L^{-1}	0.075	0.177		0.244	0.271		0.007	0.064	
Alexandrium spp.	Cells L^{-1}	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchetii	10^6Cells L^{-1}	ND	ND		ND	ND		ND	ND	

Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND		ND	ND		ND	ND		
Total Zooplankton	Individuals m^{-3}	4960	25142		13919	13919		8157	19291		

Table 3-4. Nearfield Survey WN003 (Mar 00) Data Summary

Region		Nearfield		
Parameter	**Unit**	**Min**	**Max**	**Avg**
In Situ				
Temperature	°C	3.96	4.70	4.13
Salinity	PSU	32.1	33.1	32.6
Sigma _T		25.4	26.2	25.8
Beam Attenuation	m^{-1}	0.66	4.78	1.06
DO Concentration	mgL^{-1}	10.07	12.06	11.16
DO Saturation	PCT	95.7	114.9	106.2
Fluorescence	μgL^{-1}	1.00	25.83	10.87
Chlorophyll a	μgL^{-1}	0.31	16.46	10.81
Phaeopigment	μgL^{-1}	0.13	0.75	0.45
Nutrients				
NH4	µM	0.31	6.93	1.24
NO2	µM	0.10	0.29	0.20
NO2+NO3	µM	2.71	10.79	5.96
PO4	µM	0.47	1.05	0.69
SIO4	µM	1.30	9.81	4.03
BIOSI	µM	1.20	8.00	5.50
DOC	µM	124.3	227.9	170.1
PARTP	µM	0.06	0.52	0.34
POC	µM	7.48	57.60	35.61
PON	µM	1.20	8.07	5.61
TDN	µM	13.5	29.9	20.8
TDP	µM	0.70	1.27	0.91
TSS	mgL^{-1}	0.31	1.86	1.24
Urea	µM	0.15	0.44	0.30
Productivity				
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.062	0.424	0.279
Pmax	$mgCm^{-3}h^{-1}$	4.03	42.31	29.62
Areal Production	$mgCm^{-2}d^{-1}$	2546.1	4017.2	3281.7
Chlorophyll Specific Areal Production	$mgC(mg\ Chla)^{-1}m^{-2}d^{-1}$	244.0	259.3	251.7
Respiration	μMO_2h^{-1}	0.018	0.072	0.047
Plankton				
Total Phytoplankton	10^6Cells L^{-1}	1.892	2.271	
Centric diatoms	10^6Cells L^{-1}	0.527	0.657	
Alexandrium spp.	Cells L^{-1}	1.45	1.45	
Phaeocystis pouchetii	10^6Cells L^{-1}	0.941	1.276	
Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND	
Total Zooplankton	Individuals m^{-3}	12984	40896	

Table 3-5. Combined Farfield/Nearfield Survey WF004 (Mar-Apr 00) Data Summary

		Farfield								
Region		**Boundary**			**Cape Cod Bay**			**Coastal**		
Parameter	**Unit**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
In Situ										
Temperature	°C	4.31	5.82	5.07	4.51	6.88	5.66	4.80	6.52	5.55
Salinity	PSU	30.3	33.1	32.0	30.8	32.1	31.7	31.2	32.1	31.7
Sigma _T		23.8	26.1	25.3	24.1	25.4	25.0	24.5	25.4	25.1
Beam Attenuation	m^{-1}	0.54	1.91	1.15	0.88	2.28	1.24	0.99	2.59	1.82
DO Concentration	mgL^{-1}	9.85	12.98	11.47	10.24	10.68	10.44	10.12	12.48	11.28
DO Saturation	PCT	95.1	126.7	111.4	98.3	106.7	101.8	97.5	122.7	109.9
Fluorescence	μgL^{-1}	0.09	13.69	6.37	0.62	13.18	3.53	0.18	15.42	8.39
Chlorophyll a	μgL^{-1}	0.77	21.06	7.19	2.25	9.35	4.90	3.13	14.29	8.11
Phaeopigment	μgL^{-1}	0.42	3.59	1.03	0.27	1.81	0.78	0.10	2.17	1.56
Nutrients										
NH4	µM	0.19	4.51	1.14	0.27	2.88	1.62	0.23	3.50	1.19
NO2	µM	0.01	0.19	0.08	0.03	0.11	0.05	0.03	0.14	0.08
NO2+NO3	µM	0.04	9.47	3.40	0.12	2.81	0.79	0.11	4.85	1.53
PO4	µM	0.23	1.01	0.52	0.42	0.68	0.49	0.28	0.80	0.45
SIO4	µM	4.32	11.02	6.85	1.76	4.46	2.68	1.72	6.55	3.73
BIOSI	µM	1.60	3.60	2.30	0.80	2.10	1.22	1.50	3.00	2.13
DOC	µM	152.3	352.9	243.9	139.0	340.2	230.0	182.7	424.4	275.8
PARTP	µM	0.03	0.17	0.10	0.24	0.44	0.34	0.14	0.53	0.25
POC	µM	8.58	64.10	34.18	32.20	66.20	45.92	24.50	73.80	52.71
PON	µM	2.58	10.20	6.14	5.35	9.57	6.85	5.54	12.90	9.80
TDN	µM	10.0	23.0	18.8	10.7	13.7	12.6	13.8	26.9	19.1
TDP	µM	0.51	1.10	0.88	0.62	0.78	0.69	0.60	0.87	0.74
TSS	mgL^{-1}	0.84	1.52	1.09	0.78	1.56	0.99	1.24	3.47	2.03
Urea	µM	0.02	0.47	0.16	0.08	0.34	0.16	0.15	0.87	0.39
Productivity										
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$									
Pmax	$mgCm^{-3}h^{-1}$									
Areal Production	$mgCm^{-2}d^{-1}$									
Chlorophyll Specific Areal Production	$mgC(mg\ Chla)^{-1}m^{-2}d^{-1}$									
Respiration	μMO_2h^{-1}									
Plankton										
Total Phytoplankton	10^6Cells L^{-1}	3.555	7.467		1.386	3.765		4.700	12.682	
Centric diatoms	10^6Cells L^{-1}	0.015	0.082		0.011	0.032		0.008	0.159	
Alexandrium spp.	Cells L^{-1}	ND	ND		3.00	3.00		3.05	3.05	

Phaeocystis pouchetii	10^6Cells L^{-1}	3.233	7.121		0.233	2.138		4.332	11.512	
Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND		ND	ND		ND	ND	
Total Zooplankton	Individuals m^{-3}	4776	9863		8354	45877		4978	33108	

Table 3-5. Combined Farfield/Nearfield Survey WF004 (Mar -Apr 00) Data Summary (continued)

		Farfield								
Region		**Harbor**			**Offshore**			**Nearfield**		
Parameter	**Unit**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
In Situ										
Temperature	°C	5.33	7.07	6.23	4.51	6.34	5.02	4.80	6.55	5.16
Salinity	PSU	29.5	33.6	31.4	31.5	32.4	31.9	31.2	32.2	32.0
Sigma _T		23.0	26.4	24.6	24.9	25.6	25.2	24.5	25.5	25.3
Beam Attenuation	m^{-1}	1.69	2.94	2.09	0.58	2.07	1.16	0.72	1.94	1.25
DO Concentration	mgL^{-1}	11.00	12.10	11.60	9.86	12.95	11.22	9.94	13.53	11.53
DO Saturation	PCT	112.6	121.7	115.2	94.3	127.2	108.7	96.1	132.8	112.2
Fluorescence	μgL^{-1}	6.54	13.86	8.89	0.19	15.76	5.56	0.16	12.64	5.30
Chlorophyll a	μgL^{-1}	7.33	19.65	10.50	0.88	11.16	5.74	1.18	10.79	5.19
Phaeopigment	μgL^{-1}	0.60	2.52	1.76	0.27	1.80	1.12	0.30	2.31	1.20
Nutrients										
NH4	µM	0.63	6.81	3.29	0.16	3.43	1.36	0.17	4.36	1.34
NO2	µM	0.07	0.31	0.17	0.00	0.17	0.08	0.00	0.21	0.08
NO2+NO3	µM	0.91	4.76	2.06	0.04	9.09	2.96	0.04	6.70	2.42
PO4	µM	0.18	0.57	0.33	0.27	0.97	0.58	0.16	0.87	0.54
SIO4	µM	2.73	9.18	3.91	2.08	9.29	5.16	1.96	6.82	4.12
BIOSI	µM	2.50	5.20	3.74	0.90	2.00	1.37	1.10	3.30	1.70
DOC	µM	162.1	485.6	276.7	153.8	418.1	295.7	124.5	593.0	227.7
PARTP	µM	0.19	0.34	0.25	0.13	0.37	0.28	0.09	0.65	0.31
POC	µM	50.30	90.00	67.93	7.16	55.00	26.28	11.20	51.90	34.52
PON	µM	8.79	14.50	11.74	2.01	8.57	4.14	2.68	9.50	5.82
TDN	µM	12.8	24.6	19.0	8.2	20.4	13.6	8.0	19.0	14.4
TDP	µM	0.61	0.91	0.72	0.51	1.08	0.72	0.50	1.05	0.76
TSS	mgL^{-1}	1.89	3.87	2.74	0.65	1.42	1.07	0.62	1.94	1.16
Urea	µM	0.15	1.52	0.62	0.08	0.15	0.13	0.08	0.15	0.10
Productivity										
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.460	0.620	0.536				0.073	0.404	0.245
Pmax	$mgCm^{-3}h^{-1}$	53.90	74.80	63.06				5.50	34.90	21.52
Areal Production	$mgCm^{-2}d^{-1}$	4125.34	4125.34	4125.34				2654.12	2882.06	2768.09
Chlorophyll Specific Areal Production	$mgC(mg\ Chla)^{-1}m^{-2}d^{-1}$	419.2	419.2	419.2				579.4	715.6	647.5
Respiration	μMO_2h^{-1}	0.116	0.201	0.158	0.061	0.133	0.085	0.051	0.184	0.121
Plankton										
Total Phytoplankton	10^6Cells L^{-1}	6.698	13.761		1.793	9.175		2.517	11.005	
Centric diatoms	10^6Cells L^{-1}	0.105	0.369		0.000	0.013		0.003	0.010	
Alexandrium spp.	Cells L^{-1}	ND	ND		ND	ND		ND	ND	

Phaeocystis pouchetii	10^6Cells L^{-1}	5.959	12.258		1.605	8.824		2.254	10.706	
Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND		ND	ND		ND	ND	
Total Zooplankton	Individuals m^{-3}	3640	22916		10419	13174		6210	12639	

Table 3-6. Nearfield Survey WN005 (May 00) Data Summary

Region		Nearfield		
Parameter	**Unit**	**Min**	**Max**	**Avg**
In Situ				
Temperature	°C	5.89	7.87	6.61
Salinity	PSU	30.3	32.5	31.5
Sigma _T		23.6	25.6	24.7
Beam Attenuation	m^{-1}	0.70	1.39	0.98
DO Concentration	mgL^{-1}	9.20	10.96	10.42
DO Saturation	PCT	91.3	112.1	104.3
Fluorescence	μgL^{-1}	1.08	3.79	2.32
Chlorophyll a	μgL^{-1}	0.28	1.57	0.73
Phaeopigment	μgL^{-1}	0.06	1.54	0.30
Nutrients				
NH4	µM	1.33	7.96	2.71
NO2	µM	0.08	0.44	0.12
NO2+NO3	µM	0.88	3.28	1.63
PO4	µM	0.44	0.78	0.60
SIO4	µM	5.68	11.27	7.99
BIOSI	µM	0.30	2.40	0.78
DOC	µM	136.0	369.4	196.7
PARTP	µM	0.07	0.34	0.15
POC	µM	7.08	34.20	15.63
PON	µM	1.75	5.94	3.20
TDN	µM	14.2	25.9	19.1
TDP	µM	0.64	0.91	0.77
TSS	mgL^{-1}	0.36	1.37	0.64
Urea	µM	0.18	0.31	0.23
Productivity				
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.012	0.060	0.029
Pmax	$mgCm^{-3}h^{-1}$	1.07	7.36	3.07
Areal Production	$mgCm^{-2}d^{-1}$	465.1	627.9	546.5
Chlorophyll Specific Areal Production	$mgC(mg\ Chla)^{-1}m^{-2}d^{-1}$	516.5	572.3	544.4
Respiration	μMO_2h^{-1}	0.020	0.098	0.058
Plankton				
Total Phytoplankton	10^6Cells L^{-1}	0.187	1.001	
Centric diatoms	10^6Cells L^{-1}	0.005	0.010	
Alexandrium spp.	Cells L^{-1}	ND	ND	
Phaeocystis pouchetii	10^6Cells L^{-1}	ND	ND	
Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND	
Total Zooplankton	Individuals m^{-3}	15799	46324	

Table 3-7. Nearfield Survey WN006 (May 00) Data Summary

Region		Nearfield		
Parameter	**Unit**	**Min**	**Max**	**Avg**
In Situ				
Temperature	°C	5.89	11.90	8.86
Salinity	PSU	29.8	32.2	30.9
Sigma _T		22.7	25.4	23.9
Beam Attenuation	m^{-1}	0.62	2.21	1.18
DO Concentration	mgL^{-1}	8.82	11.99	10.41
DO Saturation	PCT	88.2	132.9	109.8
Fluorescence	μgL^{-1}	0.06	14.67	4.72
Chlorophyll a	μgL^{-1}	0.42	12.00	5.87
Phaeopigment	μgL^{-1}	0.04	6.22	1.34
Nutrients				
NH4	µM	0.25	6.80	2.10
NO2	µM	0.00	0.22	0.06
NO2+NO3	µM	0.00	3.46	0.97
PO4	µM	0.04	1.04	0.41
SIO4	µM	0.17	18.62	5.03
BIOSI	µM	2.20	5.00	3.42
DOC	µM	123.6	299.2	190.4
PARTP	µM	0.15	0.58	0.38
POC	µM	11.70	70.40	45.20
PON	µM	2.70	10.70	6.73
TDN	µM	8.6	20.2	12.4
TDP	µM	0.30	1.03	0.50
TSS	mgL^{-1}	0.68	1.96	1.22
Urea	µM	0.12	0.91	0.42
Productivity				
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.012	0.190	0.090
Pmax	$mgCm^{-3}h^{-1}$	2.31	17.39	9.46
Areal Production	$mgCm^{-2}d^{-1}$	1401.3	1557.7	1479.5
Chlorophyll Specific Areal Production	$mgC(mg\ Chla)^{-1}m^{-2}d^{-1}$	291.8	295.5	293.7
Respiration	μMO_2h^{-1}			
Plankton				
Total Phytoplankton	10^6Cells L^{-1}	2.071	2.519	
Centric diatoms	10^6Cells L^{-1}	0.616	0.998	
Alexandrium spp.	Cells L^{-1}	2.8	9.6	
Phaeocystis pouchetii	10^6Cells L^{-1}	ND	ND	
Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND	
Total Zooplankton	Individuals m^{-3}	36201	74504	

Table 3-8. Combined Farfield/Nearfield Survey WF007 (Jun 00) Data Summary

		Farfield								
Region		**Boundary**			**Cape Cod Bay**			**Coastal**		
Parameter	**Unit**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
In Situ										
Temperature	°C	5.58	13.13	9.22	10.66	14.93	13.42	10.55	13.68	12.41
Salinity	PSU	29.5	32.5	31.3	30.5	31.2	30.8	29.7	31.1	30.5
Sigma _T		22.1	25.6	24.2	22.6	23.9	23.1	22.1	23.8	23.0
Beam Attenuation	m^{-1}	0.57	1.40	0.91	0.82	1.77	1.42	0.76	2.51	1.73
DO Concentration	mgL^{-1}	8.83	10.49	9.90	8.05	9.65	9.29	8.59	9.67	9.12
DO Saturation	PCT	86.9	118.7	105.4	88.4	114.9	107.9	99.3	108.2	103.4
Fluorescence	μgL^{-1}	0.03	7.18	2.70	0.31	9.86	5.79	0.77	7.17	3.76
Chlorophyll a	μgL^{-1}	0.34	4.37	2.05	2.09	7.50	4.31	1.47	7.77	3.88
Phaeopigment	μgL^{-1}	0.32	1.41	0.74	0.73	3.09	1.25	0.79	2.50	1.55
Nutrients										
NH4	µM	0.21	18.61	2.92	0.33	3.53	1.05	0.99	10.58	3.36
NO2	µM	0.02	0.23	0.10	0.00	0.09	0.03	0.06	0.41	0.16
NO2+NO3	µM	0.01	6.92	2.41	0.01	0.53	0.15	0.28	2.89	1.00
PO4	µM	0.20	1.18	0.56	0.18	0.41	0.26	0.29	0.86	0.43
SIO4	µM	0.71	21.90	5.97	3.64	10.19	4.71	2.15	10.29	5.13
BIOSI	µM	0.30	3.10	1.35	0.80	1.80	1.40	1.50	4.50	3.20
DOC	µM	166.6	342.1	253.4	156.4	315.6	207.2	143.8	272.2	190.0
PARTP	µM	0.09	0.25	0.18	0.15	0.26	0.21	0.15	0.40	0.30
POC	µM	9.50	54.20	28.98	14.40	34.50	29.00	17.80	61.20	35.43
PON	µM	1.28	8.79	4.58	2.49	5.36	4.25	2.71	9.29	5.69
TDN	µM	10.8	19.9	13.9	10.4	15.1	12.0	13.8	23.8	17.8
TDP	µM	0.40	1.02	0.64	0.44	0.62	0.52	0.51	0.98	0.70
TSS	mgL^{-1}	0.57	1.73	0.90	0.79	2.56	1.21	1.13	2.32	1.80
Urea	µM	0.39	0.39	0.39	0.33	0.53	0.45	0.33	0.99	0.54
Productivity										
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$									
Pmax	$mgCm^{-3}h^{-1}$									
Areal Production	$mgCm^{-2}d^{-1}$									
Chlorophyll Specific Areal Production	$mgC(mg\ Chla)^{-1}m^{-2}d^{-1}$									
Respiration	μMO_2h^{-1}									
Plankton										
Total Phytoplankton	10^6Cells L^{-1}	0.313	0.807		0.888	2.398		0.804	2.513	
Centric diatoms	10^6Cells L^{-1}	0.004	0.026		0.012	0.032		0.051	0.250	
Alexandrium spp.	Cells L^{-1}	ND	ND		ND	ND		1.8	1.9	
Phaeocystis pouchetii	10^6Cells L^{-1}	ND	ND		ND	ND		ND	ND	

Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND		ND	ND	ND	ND
Total Zooplankton	Individuals m^{-3}	92122	135943		81366	96033	118568	144149

Table 3-8. Combined Farfield/Nearfield Survey WF007 (Jun 00) Data Summary (continued)

		Farfield								
Region		**Harbor**			**Offshore**			**Nearfield**		
Parameter	**Unit**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
In Situ										
Temperature	°C	13.16	14.79	13.82	5.75	13.32	10.30	6.71	14.55	11.36
Salinity	PSU	27.3	29.9	29.0	30.2	32.3	31.0	29.5	31.8	30.8
Sigma _T		20.1	22.3	21.6	22.7	25.5	23.8	21.9	25.0	23.4
Beam Attenuation	m^{-1}	2.23	5.00	3.61	0.62	2.11	1.16	0.63	3.28	1.26
DO Concentration	mgL^{-1}	8.00	8.80	8.35	8.26	10.37	9.60	8.52	10.30	9.61
DO Saturation	PCT	93.4	102.5	96.7	85.8	117.4	104.5	85.8	114.3	106.8
Fluorescence	μgL^{-1}	5.23	13.52	7.99	0.04	9.61	4.02	0.83	16.34	4.19
Chlorophyll a	μgL^{-1}	3.92	11.05	8.31	0.11	7.77	3.80	0.30	10.75	3.06
Phaeopigment	μgL^{-1}	2.67	8.07	4.30	0.54	2.74	1.38	0.06	9.32	1.10
Nutrients										
NH4	µM	4.40	20.62	12.32	0.13	5.38	2.15	0.16	6.22	1.44
NO2	µM	0.28	0.59	0.46	0.01	0.23	0.12	0.00	0.22	0.06
NO2+NO3	µM	2.92	6.82	4.27	0.03	5.65	1.71	0.01	4.41	0.48
PO4	µM	0.54	1.27	0.97	0.17	1.22	0.54	0.14	1.11	0.35
SIO4	µM	5.36	23.78	12.67	1.31	12.36	5.33	1.08	21.88	3.65
BIOSI	µM	4.40	11.40	6.71	0.10	2.00	1.18	0.20	3.50	1.68
DOC	µM	206.9	361.3	265.8	212.1	346.3	272.8	133.9	455.9	238.7
PARTP	µM	0.41	0.89	0.65	0.01	0.39	0.18	0.11	0.55	0.19
POC	µM	27.80	75.50	51.42	16.80	45.50	32.17	10.60	59.80	24.52
PON	µM	4.72	12.50	8.65	2.82	7.29	5.12	1.77	9.07	3.88
TDN	µM	21.1	62.6	35.2	14.8	23.3	19.7	8.7	51.6	16.0
TDP	µM	0.83	1.47	1.16	0.45	1.18	0.62	0.39	1.07	0.57
TSS	mgL^{-1}	2.74	8.44	4.81	0.65	1.56	1.02	0.40	2.37	1.08
Urea	µM	0.46	0.86	0.68	0.26	0.26	0.26	0.13	0.26	0.16
Productivity										
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.066	0.089	0.076				0.006	0.067	0.044
Pmax	$mgCm^{-3}h^{-1}$	10.12	20.72	15.55				0.40	11.91	6.03
Areal Production	$mgCm^{-2}d^{-1}$	414.2	414.2	414.2				961.8	1116.4	1039.1
Chlorophyll Specific Areal Production	$mgC(mg\ Chla)^{-1}m^{-2}d^{-1}$	38.2	38.2	38.2				342.3	348.2	345.2
Respiration	μMO_2h^{-1}	0.181	0.188	0.185	0.047	0.139	0.108	0.050	0.141	0.088
Plankton										
Total Phytoplankton	10^6Cells L^{-1}	1.660	3.383		0.429	1.860		0.726	1.495	
Centric diatoms	10^6Cells L^{-1}	0.146	0.959		0.002	0.106		0.002	0.216	
Alexandrium spp.	Cells L^{-1}	1.75	1.75		ND	ND		ND	ND	
Phaeocystis pouchetii	10^6Cells L^{-1}	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND		ND	ND		ND	ND	

Total Zooplankton	Individuals m^{-3}	30403	91262	132443	186991	59395	289816	

Table 3-9. Nearfield Survey WN008 (Jul 00) Data Summary

Region		Nearfield		
Parameter	**Unit**	**Min**	**Max**	**Avg**
In Situ				
Temperature	°C	6.56	18.11	10.20
Salinity	PSU	30.9	32.1	31.7
Sigma _T		22.3	25.2	24.3
Beam Attenuation	m^{-1}	0.57	3.04	1.09
DO Concentration	mgL^{-1}	7.94	12.37	9.64
DO Saturation	PCT	82.1	147.2	105.5
Fluorescence	μgL^{-1}	0.02	21.47	3.76
Chlorophyll a	μgL^{-1}	0.44	20.85	4.71
Phaeopigment	μgL^{-1}	0.19	6.09	1.66
Nutrients				
NH4	µM	0.12	4.05	1.59
NO2	µM	0.01	0.46	0.19
NO2+NO3	µM	0.10	6.57	2.47
PO4	µM	0.13	1.21	0.63
SIO4	µM	1.10	21.37	5.79
BIOSI	µM	0.40	4.80	1.89
DOC	µM	134.3	336.9	207.1
PARTP	µM	0.09	0.74	0.31
POC	µM	6.91	80.30	34.75
PON	µM	1.55	12.40	5.45
TDN	µM	8.6	44.4	18.4
TDP	µM	0.42	1.19	0.73
TSS	mgL^{-1}	0.62	2.49	1.16
Urea	µM	0.11	0.17	0.16
Productivity				
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.010	0.403	0.139
Pmax	$mgCm^{-3}h^{-1}$	0.62	63.30	18.43
Areal Production	$mgCm^{-2}d^{-1}$	1270.1	3762.9	2516.5
Chlorophyll Specific Areal Production	$mgC(mg\ Chla)^{-1}m^{-2}d^{-1}$	538.8	557.0	547.9
Respiration	μMO_2h^{-1}	0.032	0.333	0.143
Plankton				
Total Phytoplankton	10^6Cells L^{-1}	0.546	3.661	
Centric diatoms	10^6Cells L^{-1}	0.027	1.746	
Alexandrium spp.	Cells L^{-1}	ND	ND	
Phaeocystis pouchetii	10^6Cells L^{-1}	ND	ND	
Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND	
Total Zooplankton	Individuals m^{-3}	84356	146097	

Table 3-10. Nearfield Survey WN009 (Jul 00) Data Summary

Region		Nearfield		
Parameter	**Unit**	**Min**	**Max**	**Avg**
In Situ				
Temperature	°C	6.88	17.93	12.82
Salinity	PSU	30.9	32.1	31.5
Sigma _T		22.3	25.1	23.6
Beam Attenuation	m^{-1}	0.57	2.23	1.15
DO Concentration	mgL^{-1}	7.88	10.46	9.14
DO Saturation	PCT	84.4	133.2	105.4
Fluorescence	μgL^{-1}	0.16	4.60	0.98
Chlorophyll a	μgL^{-1}	0.06	4.49	1.21
Phaeopigment	μgL^{-1}	0.10	1.04	0.44
Nutrients				
NH4	µM	0.21	23.14	2.24
NO2	µM	0.01	0.52	0.17
NO2+NO3	µM	0.03	7.48	1.56
PO4	µM	0.08	1.20	0.58
SIO4	µM	1.02	20.67	5.57
BIOSI	µM	0.20	3.80	1.07
DOC	µM	153.5	386.1	224.0
PARTP	µM	0.04	0.60	0.31
POC	µM	3.48	70.40	33.31
PON	µM	0.75	10.50	5.04
TDN	µM	10.5	58.1	17.2
TDP	µM	0.31	1.14	0.66
TSS	mgL^{-1}	0.53	1.91	1.06
Urea	µM	0.11	0.76	0.40
Productivity				
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.003	0.121	0.056
Pmax	$mgCm^{-3}h^{-1}$	0.39	15.59	6.25
Areal Production	$mgCm^{-2}d^{-1}$	928.7	1433.7	1181.2
Chlorophyll Specific Areal Production	$mgC(mg\ Chla)^{-1}m^{-2}d^{-1}$	662.7	913.1	787.9
Respiration	μMO_2h^{-1}	0.033	0.291	0.148
Plankton				
Total Phytoplankton	10^6Cells L^{-1}	1.525	3.050	
Centric diatoms	10^6Cells L^{-1}	0.131	1.150	
Alexandrium spp.	Cells L^{-1}	20.7	20.7	
Phaeocystis pouchetii	10^6Cells L^{-1}	ND	ND	
Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND	
Total Zooplankton	Individuals m^{-3}	273860	274935	

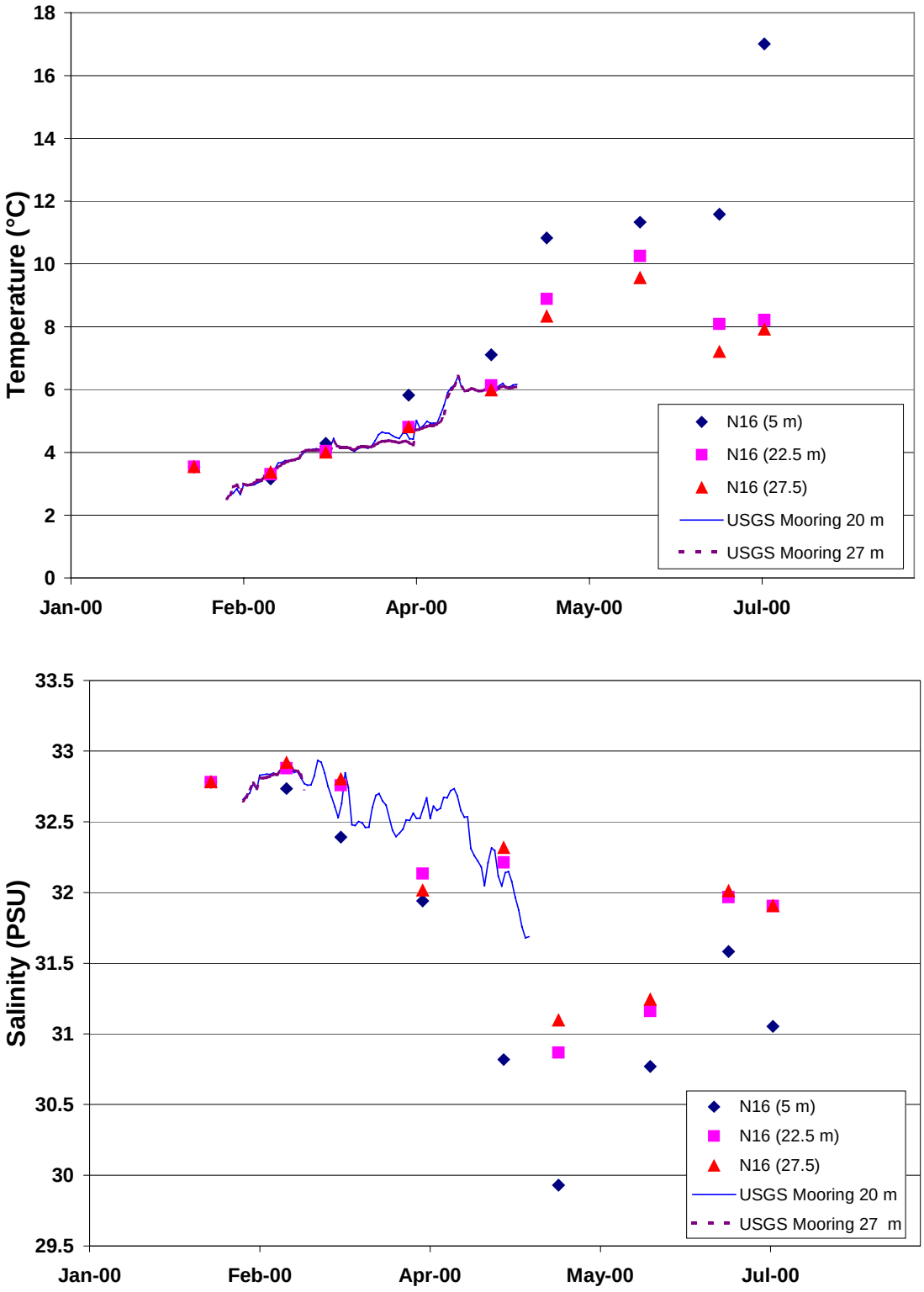


Figure 3-1. USGS Temperature and Salinity Mooring Data Compared with Nearfield Station N16

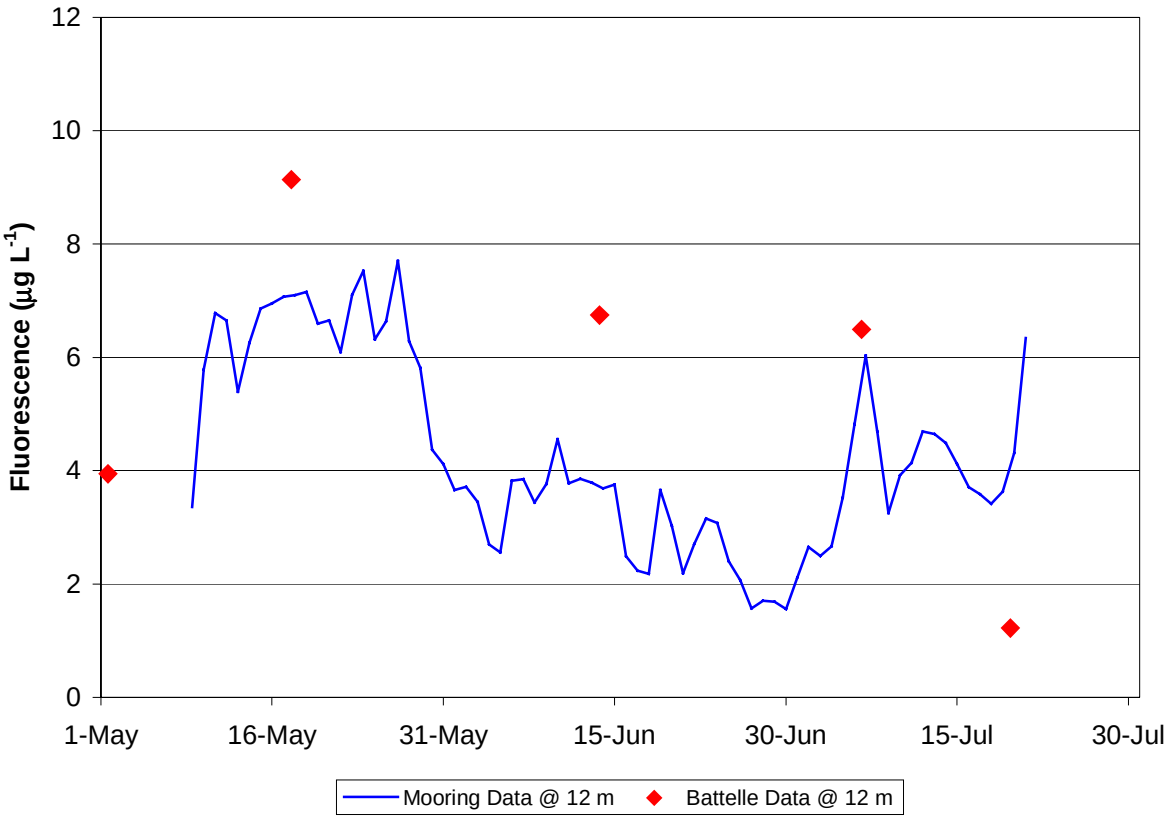


Figure 3-2. MWRA and Battelle *In Situ* Wetstar Fluorescence Data (MWRA Data Acquired at 12 m on USGS Mooring and Battelle Data Acquired at 12 m at Station N16)

4.0 RESULTS OF WATER COLUMN MEASUREMENTS

Data presented in this section are organized by type of data and survey. Physical data, including temperature, salinity, density, and beam attenuation are presented in Section 4.1. Nutrients, chlorophyll *a*, and dissolved oxygen are discussed in Section 4.2. Finally a summary of the major results of water column measurements (excepting biological measurements) is provided in Section 4.3.

Four of the nine surveys conducted during the semi-annual period were combined farfield/nearfield surveys. The first two combined surveys in early and late February (WF001 and WF002) were conducted prior to stratification of the water column. The onset of stratification was observed during the April combined survey (WF004) at the shallow stations in Boston Harbor and at the deep boundary stations. In both of these areas, lower salinity surface waters drove the density gradient. The last combined survey (WF007) was conducted in June and a strong density gradient was observed at the offshore and boundary stations. At the shallower coastal, Cape Cod Bay, Boston Harbor, and western nearfield stations, stratification was still relatively weak in June. Data collected during the farfield surveys were evaluated for trends in regional water masses throughout Boston Harbor, Massachusetts Bay and Cape Cod Bay. The variation of regional surface water properties is presented using contour plots of surface water parameters derived from the surface (A) water sample. Classifying data by regions allows comparison of the horizontal distribution of water mass properties over the farfield area.

The vertical distribution of water column parameters is presented in the following sections along three farfield transects (Boston-Nearfield, Cohassett and Marshfield) in the survey area and one transect across the nearfield area (Figure 1-3). Examining data trends along transects provides a three-dimensional perspective of water column conditions during each survey. Nearfield surveys were conducted more frequently than farfield surveys allowing better temporal resolution of the changes in water column parameters and the onset of stratification. In addition to the nearfield vertical transect (Figure 1-3), vertical variability in nearfield data is examined and presented by comparing surface and bottom water concentrations (A and E depths) and by plotting individual parameters with depth in the water column. A complete set the surface contour maps, vertical transect plots and parameter scatter plots is provided in Appendices B, C and D, respectively.

4.1 Physical Characteristics

4.1.1 Temperature\Salinity\Density

The timing of the annual setup of vertical stratification in the water column is an important determinant of water quality, primarily because of the trend towards continuously decreasing dissolved oxygen in bottom water during the summer and early fall. The pycnocline, defined as a narrow water depth interval over which density increases rapidly, is caused by a combination of freshwater input during spring runoff and warming of surface water in the summer. Above the pycnocline the surface water is well mixed, and below the pycnocline density increases more gradually. For the purposes of this report, the water column is considered stratified when the difference between surface and bottom water density is greater than 1.0 sigma-t units (σ_t). Using this definition, stratification did not set in the nearfield until early May and even then only at the deeper stations in the eastern nearfield (Figure 4-1). The density profiles suggest that although the pycnocline may have been developing across the eastern nearfield in May, strong stratified conditions were not established in the nearfield until July (Figure 4-2).

4.1.1.1 Horizontal Distribution

In early February (WF001), surface water temperatures were cold (2.0°C ± 2°C) across the entire farfield/nearfield area. The surface water temperatures ranged from 0.22°C at station F02 in Cape Cod Bay to 3.75°C at boundary station F29. Colder water temperatures were found in Cape Cod Bay, south shore coastal waters, and Boston Harbor and there was a clear inshore to offshore increase in temperatures (Figure 4-3). Surface water salinity was fairly uniform across the bays (32.5 ± 0.5 PSU) and also exhibited an inshore to offshore increase during WF001 (Figure 4-4). Lower salinity waters (<32 PSU) were only present in Boston Harbor. Surface water temperatures had warmed slightly by late February (WF002; 3°C ± 1.5°C) and continued to be coolest to the south in Cape Cod Bay, along the south shore, and in Boston Harbor. Temperatures ranged from 1.75°C at Cape Cod Bay station F01 to 4.5°C at boundary station F27. The distribution of minimum and maximum surface temperatures followed the general trend of increasing temperatures from south to north and inshore to offshore waters. A similar inshore to offshore pattern was observed for surface salinity data with the lowest surface salinity being observed at harbor station F30 and the highest at boundary station F27.

By early April (WF004), surface water temperature had increased (6°C ± 1°C). The shallow waters in Cape Cod Bay, Boston Harbor, and along coastal areas had become warmer creating a decreasing temperature gradient from inshore to offshore (Figure 4-5). In early April, the highest surface temperature was observed at harbor station F30 (7.07°C) and the lowest at offshore station F07 (4.99°C). Surface salinity values increased from inshore to offshore (Figure 4-6) with the minimum at harbor station F30 (29.45 PSU) and the maximum at nearfield station N16 (32.08 PSU). Lower surface salinity was observed at the stations off of Cape Ann (F26 and F27), which is indicative of the spring freshet of lower salinity surface waters from the Gulf of Maine and rivers to the north. In fact, flow in the Merrimack River increased from February through March reaching maximum flows in April (Figure 4-7). The Charles River followed a similar pattern with increased flow in March reaching a maximum flow rate in late April. Precipitation measured at Boston's Logan airport was correlated to the river flow data as there were four precipitation events with ~1 inch of rain in the March to April time frame.

During the June farfield/nearfield survey (WF007), surface water temperature across the farfield region ranged from a low of 11.18°C in the nearfield at station N16 to a maximum of 14.93°C in Cape Cod Bay at station F03 (Figure 4-8). Surface water temperatures were warmer to the south in Cape Cod Bay, southern Massachusetts Bay, and in Boston Harbor. Surface water salinity ranged from 27.33 at harbor station F30 to 31.01 at nearfield station N01. The surface salinity pattern was similar to that seen in April, with lower salinity in Boston Harbor and off of Cape Ann (Figure 4-9). This is consistent with the precipitation and flow data presented in Figure 4-7. Survey activities were delayed in June due to inclement weather that delivered significant amounts of rainfall to the region (almost 4 inches on June 6 at Logan Airport), which increased flow in the region's rivers. This is in stark contrast to drought conditions that were observed in New England during the same time period in 1999.

The changes that were observed in surface temperatures and salinity from February to April to June are indicative of the onset of seasonal stratification. By examining the temperature-salinity (T-S) plots, there is a clear change in the relationship between these two parameters between WF001 and WF007 (Figures 4-10 and 4-11). In early February, the trend within each of the regions was that increasing temperatures were concurrent with increasing salinity. The surface waters were generally cooler and less saline than bottom waters and thus the density gradient was not significant. By late February, this trend was less pronounced as surface and shallow waters warmed. The April survey

occurred during a transition period. There was relatively little difference in water temperatures over the water column, but there was a wide range of salinity. By June, seasonal stratified conditions had been established with a warmer, less saline surface layer and cooler, more saline bottom waters.

4.1.1.2 Vertical Distribution

Farfield. The water column was well mixed throughout the region during the winter and early spring of 2000. As suggested previously, the density gradient ($\Delta\sigma_t$), representing the difference between the bottom and surface water σ_t, can be used as a relative indicator of a mixed or vertically stratified water column. Surface and bottom water density decreased over the course of this period throughout the farfield area (Figure 4-12). The water column was well mixed in each of the areas during the two February surveys. During the April survey (WF004), stratified conditions ($\Delta\sigma_t \geq 1.0$) were only observed at the harbor stations. At the boundary stations, the density gradient between surface and bottom waters was slightly less than 1. The development of stratification at these stations was primarily driven by a decrease in surface salinity (Figure 4-13), as surface and bottom water temperatures remained relatively unchanged during the first three combined surveys (Figure 4-14). There was a wide range of surface salinity at the boundary stations (see Figure 4-6) and the mean data presented in Figure 4-12d and 4-13d reflect the low surface salinity measured at the stations off Cape Ann. By June (WF007), surface water temperatures had increased by ~7°C throughout the bays and the offshore and boundary areas were strongly stratified ($\Delta\sigma_t > 2.0$). At the harbor stations, the water column was still weakly stratified ($\Delta\sigma_t$ ~1.0) and the coastal and Cape Cod Bay stations remained relatively well mixed though June.

The seasonal establishment of stratified conditions was also clearly illustrated in the vertical contour plots of temperature, salinity, and sigma-T for the Boston-Nearfield, Cohassett, and Marshfield transects (Appendix C). In February, there was little variation in these parameters over the water column, though as shown in the transect plots for σ_t, there was an increase in density from inshore to offshore (Figure 4-15). In April (WF004), the physical characteristics of the water column still suggested that the water column was relatively well mixed across each of the transects, except at boundary station F27 where the density gradient between the surface and bottom waters suggests the onset of seasonal stratification (Figure 4-16). By June (WF007), a strong pycnocline had developed throughout the region (Figure 4-17). The onset of stratification in the spring is usually related to a freshening of the surface waters and then as the surface temperatures increase the density gradient or degree of stratification increases. Such was the case in the spring of 2000 as shown in Figures 4-18 and 4-19, the freshening of the surface layer was coincident with the decrease in surface density and the onset of stratification in April at station F27 and in June across the transects. Also in June, the temperature gradient between surface and bottom waters was a contributing factor to the density gradient observed (Figure 4-20). A complete set of farfield transect plots of physical water properties is provided in Appendix C.

Nearfield. The onset of stratification can be observed more clearly from the data collected in the nearfield area. The nearfield surveys are conducted on a more frequent basis and thus provide a more detailed picture of the physical characteristics of the water column. As illustrated in Figure 4-21, the water column was still well mixed in early April (WF004) and did not begin to show signs of stratification until early May (WN005). In June (WF007), the storms that occurred early in the month contributed to the continued presence of relatively weak stratification along the nearfield transect. By July (WN008), a strong density gradient ($\Delta\sigma_t > 2$) was established across the nearfield area. The physical characteristics that led to the establishment of stratified conditions are detailed below.

The gradient between surface and bottom water salinity remained relatively weak (<0.5 PSU) until the early May (Figure 4-22). At the inner nearfield stations, there was little variation in the

magnitude of the salinity gradient from February to July. At the other nearfield stations, surface salinity decreased by ~ 1 PSU while bottom salinity increased slightly from early April to early May. The decrease in surface salinity in May resulted from increased runoff to the coastal waters and the resulting salinity gradient that developed initiated the onset of stratification. By mid-May (WN006), surface salinity at the outer nearfield stations reached a minimum for the time period of ~30 PSU. Salinity minima for the surface waters at the inner nearfield stations were reached in June (WF007) and bottom water salinity minima were also observed during this survey (Figure 4-22). The input of fresher water from coastal runoff and the mixing associated with the storms led to a reduction in stratification in June (see Figure 4-1).

The nearfield water column was well mixed with respect to temperature (Figure 4-23) during the first five surveys of 2000. It was not until mid-May (WN006) that temperatures increased more substantially in the surface water than the bottom water. During this survey, there was a 3-4°C gradient between the surface and bottom waters (11-12°C versus 6-9 °C, respectively). The gradient had decreased by June due to the storm mixing events. By July, bottom water temperatures had become relatively stable at ~8°C, while surface water temperatures continued to increase. The increased temperature gradient between surface and bottom waters (Δ of ~8°C) resulted in a stronger density gradient in July.

4.1.2 Transmissometer Results

Water column beam attenuation was measured along with the other *in situ* measurements at all nearfield and farfield stations. The transmissometer determines beam attenuation by measuring the percent transmission of light over a given path length in the water. The beam attenuation coefficient (m^{-1}) is indicative of particulate concentration in the water column. The two primary sources of particles in coastal waters are biogenic material (plankton or detritus) or suspended sediments. Beam attenuation data are often evaluated in conjunction with fluorescence data to ascertain source of the particulate materials (phytoplankton versus detritus or suspended sediments).

During both of the February surveys (WF001 and WF002), surface water beam attenuation was relatively low ranging from 0.65 to 1.73 m^{-1} in early February and 0.92 to 1.76 m^{-1} in late February. The maximum values during each survey were measured in Boston Harbor. Generally, there was a decrease from inshore to offshore with elevated values being observed in the harbor and coastal waters decreasing across the nearfield and offshore. By early April (WF007), beam attenuation had increased in the harbor, coastal and western nearfield waters (Figure 4-24). The relatively high beam attenuation values observed at these stations were concomitant with high surface water fluorescence values associated with the winter/spring *Phaeocystis* bloom (see Sections 4.2.2 and 5.3). In April, the highest surface water beam attenuation values were found at the harbor and nearby coastal stations (2.47 m^{-1} at F25) and values tended to decrease with distance from the harbor. During the June survey (WF007), beam attenuation in the surface water exhibited a similar decrease in values from inshore to offshore stations and was indicative of an increase in water clarity away from Boston Harbor. In June, high surface water beam attenuation values were again observed at the harbor and nearby coastal stations (3.97 m^{-1} at F23) and values decreased further offshore.

The clear inshore to offshore horizontal gradient of decreasing beam attenuation away from Boston Harbor and the effect of the April *Phaeocystis* bloom can also be seen along the Boston-Nearfield transect (Figure 4-25). In February (WF001), elevated beam attenuation values were only present at harbor station F23. Although the harbor signal was still seen, the primary factor affecting beam attenuation in April (WF004) was the occurrence of the system wide winter/spring bloom. The pattern in transect plots of beam attenuation and fluorescence for this survey are nearly identical

(see Figure 4-36). By June (WF007), a strong harbor signal dominated the inshore to offshore trends in beam attenuation along the Boston-Nearfield transect.

4.2 Biological Characteristics

4.2.1 Nutrients

Nutrient data were preliminarily analyzed using x/y plots of nutrient depth distribution, nutrient/nutrient relationships, and nutrient/salinity relationships (Appendix D). As with the physical characteristics, surface water contour maps (Appendix B) and vertical contours from select transects (Appendix C) were also produced from the nutrient data to illustrate the spatial variability of these parameters.

The nutrient data for February to July 2000 generally followed the typical progress of seasonal events in the Massachusetts and Cape Cod Bays. Maximum nutrient concentrations were observed in early February when the water column was well mixed and biological uptake of nutrients was limited. The winter/spring 'bloom' reduced nutrient concentrations in the surface waters from March through April and with the onset of stratification nutrient concentrations in the surface waters were depleted throughout much of the region by mid-May. Storm events in April and June added variability to the typical progression from winter to summer conditions. By July, seasonal stratification had resulted in persistent nutrient depleted conditions in the surface waters and ultimately to an increase in nutrient concentrations in bottom waters due to increased rates of respiration and remineralization of organic matter. The harbor signal of elevated nutrient concentrations (especially ammonium) was observed throughout this time period.

4.2.1.1 Horizontal Distribution

During this semi-annual period, the highest nutrient concentrations were consistently measured at the harbor and harbor-influenced coastal and nearfield stations. Dissolved inorganic nutrients were generally at a maximum in surface waters during the two February surveys (WF001 and WF002). As observed in 1998 and 1999, ammonium concentrations remained elevated with respect to other stations and compared to previous baseline monitoring years at station F23 near the Deer Island harbor discharge. Nutrient concentrations were lower in Cape Cod Bay than in Massachusetts Bay during the first two farfield surveys. By April (WF004), nutrient concentrations decreased throughout the region in response to the substantial *Phaeocystis* bloom that occurred in March/April 2000 (see Section 5.3), except for silicate, which remained somewhat elevated. Nitrate and phosphate concentrations remained low to depleted in June (WF007) throughout the region except in Boston Harbor and near-harbor coastal stations. Silicate concentration remained relatively high in June and ammonium concentrations increased from April to June.

In early February (WF001), the highest nutrient values were found in Boston Harbor [dissolved inorganic nitrogen (DIN) = 24.66 μM and phosphate (PO_4) = 1.41 μM at station F23] and along the boundary [nitrate (NO_3) = 10.29 μM and silicate (SiO_4) = 9.71 μM at station F27]. The lowest concentrations were observed in Cape Cod Bay at station F02 (DIN = 6.24 μM; NO_3 = 5.53 μM; SiO_4 = 2.84 μM; and PO_4 = 0.73 μM). Nutrient concentrations generally decreased outside of the harbor and from inshore to offshore.

During the late February survey (WF002), the nutrient concentrations and spatial patterns were similar to WF001 with high concentrations in the harbor and decreasing offshore, except that nutrient concentrations had decreased in Cape Cod Bay and southern Massachusetts Bay. The pattern for surface NO_3 concentrations was representative of nutrient patterns (except NH_4) during survey WF002 (Figure 4-26). The highest nutrient concentrations were again at Boston Harbor station

F23 (DIN = 60.47 μM, PO_4 = 2.21 μM, and SiO_4 = 13.47 μM) and at boundary station F27 (NO_3 = 11.95 μM). The lowest concentrations were at station F02 in Cape Cod Bay (DIN = 1.57 μM; NO_3 = 0.23 μM; SiO_4 = 0.27 μM; and PO_4 = 0.43 μM). Ammonium concentrations in Boston Harbor continued the trend of abnormally high concentrations that had been observed during the fall/winter of 1998 and during all of 1999. During WF002, NH_4 concentrations reached a maximum concentration for the semiannual time period of 47.65 μM at station F23.

The low nutrient concentrations at Cape Cod Bay stations F01 and F02 coincided with elevated chlorophyll concentrations and phytoplankton abundance (centric diatoms dominant) and suggest that a winter/spring bloom of centric diatoms may have occurred or started in Cape Cod Bay and southern Massachusetts Bay by late February (see Figure 5-17). The phytoplankton abundance, though relatively high in comparison to other coincident data, did not achieve abundances that indicate a substantial phytoplankton bloom was occurring. The very low concentrations of nitrate and silicate, however, suggest that a bloom event may have occurred prior to this early February survey. This minor bloom was superceded by the major *Phaeocystis* bloom that occurred later in the spring.

By April (WF004), nutrient concentrations had been drawn down and NO_3 and PO_4 concentrations were generally depleted (near detection limits for NO_3) across the bays (Figure 4-27). Although they had decreased substantially, the highest nutrient concentrations were still found in the harbor (DIN = 8.94 μM, PO_4 = 0.54 μM, and NH_4 = 6.75 μM at station F23 and NO_3 = 4.45 μM at station F30). Surface SiO_4 concentration was highest (11.02 μM) at boundary station F26 off of Cape Ann due to the spring freshet. The low NO_3, PO_4, and NH_4 concentrations observed in the bays in April were coincident with elevated chlorophyll concentrations and highest production rates observed during this semiannual period that were associated with the major winter/spring bloom of *Phaeocystis*. Silicate concentrations did not reach depleted levels due to the dominance of the phytoplankton assemblage by *Phaeocystis* rather than diatoms.

In June (WF007), the highest concentrations were once again found in Boston Harbor (DIN = 25.37 μM, NH_4 = 20.20 μM, and PO4 = 1.18 μM at station F23; NO_3 = 6.23 μM and SiO_4 = 17.53 μM at station F30). Nutrient concentrations outside the harbor and harbor-influenced coastal stations remained relatively low. Surface NH_4 concentrations had increased substantially from April and a strong gradient of decreasing concentrations away from the harbor and nearby coastal waters was evident (Figure 4-28). The low surface water nutrient concentrations found throughout Massachusetts and Cape Cod Bays were coincident with relatively high surface chlorophyll concentrations. Typically, surface waters have low nutrient and low chlorophyll concentrations once stratified, summer conditions are established, but this pattern was not observed in Massachusetts Bay until the nearfield surveys in July (WN008 and WN009).

4.2.1.2 Vertical Distribution

Farfield. The vertical distribution of nutrients was evaluated using vertical contours of nutrient data collected along three transects in the farfield: Boston-Nearfield, Cohassett, and Marshfield (Figure 1-3; Appendix C). During the two surveys in February (WF001 and WF002), the transect contours indicated that the water column was replete with nutrients. Nutrient concentrations decreased from inshore to offshore and there was little variation over depth except for NH_4, which tended to be higher in the surface waters. The inshore/offshore gradient was most pronounced for the NH_4 data that, as expected, clearly showed the harbor/coastal signal (Figure 4-29). The vertical distribution of NH_4 is also evident in Figure 4-29.

From late February to early April, a drastic change in nutrient concentrations and distribution had occurred. By April (WF004), surface water concentrations of NO_3, PO_4 and NH_4 had become

depleted along each of the transects as these nutrients were being taken up by the blooming *Phaeocystis* (Figure 4-30). Ammonia concentrations, although not depleted, had declined to <7 μM over the water column at Boston Harbor station F23. The utilization of these nutrients in the surface waters resulted in a strong vertical gradient of increasing concentrations with depth. As mentioned above, the surface water nutrient depletion was coincident with elevated chlorophyll concentrations and high rates of primary production. Silicate concentrations remained relatively high, as this nutrient is not used in substantial quantities by *Phaeocystis* in comparison to other phytoplankton taxa (*i.e.* diatoms).

During the final combined farfield/nearfield survey for this semiannual period, nutrient levels in the surface waters at the non-harbor-influenced stations were depleted. Ammonium concentrations still exhibited a strong harbor/coastal signal with a dominant inshore/offshore horizontal gradient of decreasing concentrations. There was a strong vertical gradient for NO_3 and PO_4 along each of the transects with very low concentrations above the pycnocline (~25 m) and replete concentrations below. High chlorophyll concentrations were observed within the surface layer along each of these transects.

Nutrient-salinity plots are useful in distinguishing water mass characteristics and in examining regional linkages between water masses (Appendix D). Dissolved inorganic nitrogen (DIN) plotted as a function of salinity for each of the combined surveys illustrates the transition from winter to summer conditions that was evident for each of the nutrients. During the February surveys, the DIN-salinity plots exhibited a negative correlation between DIN and salinity (Figure 4-31a). This relationship is indicative of winter conditions when the water column is not stratified and the harbor and coastal waters are a source of low salinity, nutrient rich waters, but there also appears to be a slight increase in DIN concentrations at high salinity values for the deeper bottom waters. By April, high productivity in the surface waters decreased DIN concentrations substantially at lower salinity even at the normally nutrient-rich Boston Harbor stations (Figure 4-31b). The summer relationship between DIN and salinity was more evident in the data from Cape Cod Bay, nearfield, offshore and boundary areas – low concentrations surface waters and concentrations increasing with depth, but usually in the summer the surface and bottom waters more closely correspond to changes in salinity. In early April, the water column across most of the bays was still relatively well mixed and, although the nutrient concentrations were lower in the surface versus bottom waters, there was no sharp trend with salinity, except at the boundary stations that were affected by the spring freshet. In June (WF007), elevated DIN concentrations were still found at lower salinity in Boston Harbor and harbor-influenced stations (coastal and western nearfield), but summer conditions were evident in the rest of Massachusetts and Cape Cod Bays (Figure 4-32a). This is clearer when the NH_4 harbor signal is removed from the figure and only NO_3+NO_2 is presented (Figure 4-32b). The low DIN and NO_3+NO_2 concentrations at intermediate salinity represent the surface waters throughout the bays where biological activity has consumed DIN from both horizontal (harbor/coastal) and vertical (bottom waters) sources.

Nearfield. The nearfield surveys are conducted more frequently and provide a high resolution of the temporal variation in nutrient concentrations over the semi-annual period. In previous sections, the transition from winter to summer physical and nutrient characteristics has been discussed. For the nearfield, the transition from winter to summer nutrient regimes can be demonstrated by examining the variations in surface and bottom water NO_3 concentrations. In Figure 4-33, surface and bottom water NO_3 concentrations from five nearfield stations representing the four corners (N01, N04, N07, and N10) and the center (N21) of the nearfield were plotted for each of the nine surveys conducted this period. The highest surface water NO_3 concentrations were observed during the two surveys in February and generally decreased over the course of this period. By March (WN003), surface water nutrient concentrations had begun to decrease with the beginning of the winter/spring bloom. Bottom

water NO_3 concentrations remained high from February through March although there was a slight decrease in concentrations in March at some of the nearfield stations.

By early April, NO_3 concentrations had become depleted and perhaps nutrient limiting in surface waters across the nearfield except at station N10, which is often influenced by tidal flow from Boston Harbor. Bottom water continued to decline, but remained replete at depth (4-6 μM). From early April to early May, there was an increase in surface water NO_3 concentrations, while bottom water concentrations continued to decline. This suggests that a mixing event may have occurred following the April survey after the end of the *Phaeocystis* bloom and prior to establishment of more stratified conditions in May. By mid-May (WN006), surface water nutrient concentrations were again depleted and remained this way through July. Bottom water NO_3 concentrations remained low (<3 μM) from May to June and then increased in July.

The relationship of nutrients to salinity in the nearfield followed the trend discussed above for the whole region (see Appendix D). Although it is a relatively homogeneous area, the relationships between nutrients and salinity in the nearfield exhibited some of the variability seen in the various farfield areas. This variability was associated with the input of nutrients and less saline water from the harbor and coastal waters. In February, nutrient concentrations tended to decrease with increasing salinity. In March and April, nutrient concentrations decreased in the lower salinity surface waters due to biological utilization. In May and June, the nearfield continued the transition from winter to summer nutrient conditions, but because the mixing associated with late spring storms summer nutrient conditions were not established in the nearfield until July. By July, nutrient concentrations started to increase in the bottom more saline waters due to remineralization at depth. The nutrient-salinity plots exhibited the typical summer relationship of increasing nutrient concentrations with increasing salinity (and depth) and the lower salinity surface waters being depleted or nearly depleted of nutrients.

An examination of the nutrient-nutrient plots showed that surface waters were generally depleted in DIN relative to PO_4 and SiO_4 in the nearfield for the entire semi-annual period (Appendix D). The DIN:PO_4 ratio was generally less than the Redfield value of 16 at the nearfield stations from February to June and decreased to approximately 4 in July. For the entire period, the nearfield waters were depleted in DIN versus SiO_4, which did not reach low concentrations until mid-May.

4.2.2 Chlorophyll *a*

Chlorophyll concentrations (based on *in situ* fluorescence measurements) were high in the nearfield during the winter/spring *Phaeocystis* bloom in March and April, high throughout the bays in April, and generally decreased over the remainder of the period though relatively high subsurface maxima were observed through July. The high chlorophyll concentrations in the nearfield during the winter/spring period of 2000 were a continuation of the elevated concentrations observed in 1999. The mean chlorophyll concentration for the nearfield for winter/spring (February through April) of 2000 was 5.03 μgL^{-1}, which is greater than any previous winter/spring mean obtained for the nearfield during the baseline monitoring period. The second highest winter/spring mean was observed during 1999 (3.83 μgL^{-1}). The 2000 winter/spring mean exceeded the chlorophyll threshold value that had been calculated as two times the baseline mean for 1992 to 1998 (4.76 μgL^{-1}; note the threshold will be recalculated based on all data from 1992 through August 2000). These very high winter/spring chlorophyll concentrations were coincident with unprecedented phytoplankton abundances during the *Phaeocystis* bloom. The back-to-back years with winter/spring chlorophyll concentrations that exceeded the proposed threshold level based on 1992-1998 data is a topic that will be discussed in detail in the 2000 Annual Water Column Report.

In Cape Cod Bay, elevated chlorophyll concentrations were found during the two February surveys (mean of 8.49 μgL^{-1} for WF001 and 8.98 μgL^{-1} for WF002). The maximum survey mean chlorophyll values for the other farfield areas were all observed during the April survey (WF004). Chlorophyll concentrations were high during the April survey in the nearfield, but the maximum survey mean concentration (11.24 μgL^{-1}) was during the March survey (WN003).

4.2.2.1 Horizontal Distribution

Surface chlorophyll concentrations were relatively high throughout the region during the two surveys in February. In early February (WF001), surface chlorophyll values were generally <3 μgL^{-1} in the bays with values >3 μgL^{-1} at some offshore and boundary stations to the northeast. The highest surface chlorophyll concentration was at coastal station F05 (8.88 μgL^{-1}). By late February, surface chlorophyll concentrations in Cape Cod Bay had increased to >7 μgL^{-1} with a maximum concentration of 11.09 μgL^{-1} at station F02 (Figure 4-34). This increase correlated with a doubling of phytoplankton abundance in the surface waters (about a 2 to 3 fold increase at mid-depth), which was primarily due to a large increase in the abundance of centric diatoms. These elevated surface chlorophyll concentrations were also coincident with low nutrient concentrations in comparison to Massachusetts Bay, which was due to the biological drawdown of nutrients in this area. Surface chlorophyll concentrations decreased from relatively high values in southern Massachusetts Bay to low values in the northern bay and in Boston Harbor.

During the April survey (WF004), surface chlorophyll concentrations were high in Boston Harbor and near-harbor coastal and nearfield waters (Figure 4-35). The maximum surface chlorophyll concentration was at coastal station F24 (10.65 μgL^{-1}). In Cape Cod Bay, concentrations had decreased from late February to April to <3 μgL^{-1}. Surface chlorophyll concentrations had increased in southern Massachusetts Bay and at the boundary stations, except for station F26 off of Cape Ann. Low chlorophyll concentrations were seen from the Cape Ann station down into the eastern nearfield area (<1 μgL^{-1} for much of northern Massachusetts Bay). The high chlorophyll concentrations were coincident with very high abundances of *Phaeocystis* from 4 to 12 million cells L^{-1} in Boston Harbor and western Massachusetts Bay (see Figure 5-18).

Nearfield surface chlorophyll decreased sharply from April (WF004) to May (WN005). In early May, surface chlorophyll concentrations ranged from 1 to 2.5 μgL^{-1}, but by mid-May (WN006) surface chlorophyll had increased again to 0.29-11.62 μgL^{-1} with the maximum at station N10 and values decreasing further offshore. The decrease in nearfield surface chlorophyll concentrations from April to early May and subsequent increase by mid-May were associated with abrupt changes in the phytoplankton community assemblage. Following the decline of the winter/spring *Phaeocystis* bloom, nearfield surface phytoplankton abundance decreased from 4-6 million cells L^{-1} in April to ~1 million cells L^{-1} in early May. By mid-May, chlorophyll concentrations had again increased and phytoplankton abundance had more than doubled primarily due to an increase in centric diatoms (see Figure 5-14).

By June (WF007), the phytoplankton assemblage throughout the farfield was dominated by microflagellates and the regional pattern in surface chlorophyll was generally an inshore to offshore decrease. The chlorophyll concentrations at the Boston Harbor and near-harbor coastal and nearfield stations were high ranging from 4.41 μgL^{-1} at station F25 to 16.34 μgL^{-1} at station N10. Elevated surface chlorophyll concentrations (5-8.5 μgL^{-1}) were also observed at southern coastal and offshore Massachusetts Bay stations. Chlorophyll values decreased further offshore to <3 μgL^{-1} in the western nearfield, offshore, boundary, and Cape Cod Bay areas. This was coincident with an inshore to offshore decrease in nutrient concentrations and NO_3 depletion in the surface waters throughout the bays. Surface chlorophyll concentrations decreased in the nearfield by July, but an inshore to

offshore gradient of decreasing values continued to be observed with the maximum surface chlorophyll concentration being at harbor-influenced station N10 during both July surveys.

4.2.2.2 Vertical Distribution

Farfield. The vertical distribution of chlorophyll was evaluated using vertical contours of *in situ* fluorescence data collected along three east/west transects in the farfield: Boston-Nearfield, Cohassett, and Marshfield (Figure 1-3; Appendix C). In early February (WF001), chlorophyll concentrations along the Boston-Nearfield and Cohassett transects were relatively low (<5 μgL^{-1}) and higher concentrations (>10 μgL^{-1}) were found along the Marshfield transect. There was an inshore to offshore decrease in chlorophyll along all three of the transects. The high chlorophyll concentrations along the Marshfield transect were coincident with elevated chlorophyll concentrations further to the south in Cape Cod Bay and with relatively high phytoplankton abundances at station F06. By late February (WF002), chlorophyll concentrations along the Marshfield transect had decreased to 1-7 μgL^{-1} and concentrations along the other two transects were usually <1 μgL^{-1} except for inshore surface waters and along a subsurface layer (5-20 m) where they ranged from 1 to 3 μgL^{-1}.

In April (WF004), surface and subsurface chlorophyll concentrations had increased substantially along the transects (Figure 4-36). Along the Boston-Nearfield transect, surface chlorophyll concentrations were at a maximum at inshore stations F23 and F24 (>9 μgL^{-1}), while a subsurface chlorophyll maximum at 15-20 m was present further offshore through the nearfield to boundary station F27. The highest chlorophyll concentrations were >15 μgL^{-1} in the subsurface layer at stations F19 and F27. A similar pattern was seen along the Cohassett transect with the highest chlorophyll concentrations (>15 μgL^{-1}) at coastal station F14 at depth. Further to the south along the Marshfield transect, chlorophyll values were somewhat lower (5-11 μgL^{-1}) throughout the upper 25 m. The chlorophyll and phytoplankton data were generally consistent with higher subsurface chlorophyll concentrations and phytoplankton abundance (see Figure 5-18).

Chlorophyll concentrations had decreased by the June survey (WF007). The patterns along the transects did not show the typical progression to summer conditions of elevated chlorophyll concentrations near Boston Harbor and at the pycnocline. Instead concentrations were relatively consistent across each transect, except that they were lower at the furthest offshore station, and were generally at a maximum in the surface waters (Figure 4-37). Phytoplankton abundance, however, was higher in the mid-depth samples in comparison to the surface samples and each was dominated by microflagellates during the June survey.

Nearfield. Chlorophyll concentrations for the surface, mid-depth, and bottom waters of all nearfield stations were averaged and plotted for each of the nearfield surveys (Figure 4-38). The mid-depth sample was collected at the subsurface chlorophyll maximum, if present. The mean chlorophyll concentrations were low (~2 μgL^{-1}) and consistent over depth in early February. By late February, subsurface chlorophyll concentrations had increased at mid-depth (~3 μgL^{-1}). In March, chlorophyll values increased substantially and reached maxima for the time period for each of the depths. The March survey mean chlorophyll values ranged from 8.5 μgL^{-1} in the bottom waters to 13 μgL^{-1} at the subsurface chlorophyll maximum. These high chlorophyll concentrations were coincident with high production and the initiation of the winter/spring *Phaeocystis* bloom. By April, nearfield mean chlorophyll values had decreased considerably in the surface and bottom waters (~2 μgL^{-1}). The mean concentrations at the subsurface chlorophyll maximum had decreased to 9.5 μgL^{-1}. This decrease in chlorophyll concentrations occurred despite a 2-3 fold increase in phytoplankton abundance in surface waters and a 5 fold increase in abundance at mid-depth. Following the decline of the *Phaeocystis* bloom, nearfield chlorophyll concentrations decreased to <3 μgL^{-1} in early May. By mid-May, however, chlorophyll concentrations had increased in the surface and mid-depth waters

to 3 and 7.5 μgL^{-1}, respectively. This increase was coincident with a >2-fold increase in phytoplankton abundance from early to mid-May due predominantly to increases in microflagellates and centric diatoms. Nearfield chlorophyll concentrations tended to decline from mid-May through July except for a slight increase in surface chlorophyll in June and an increase at mid-depth in early July.

The vertical distribution of chlorophyll was also examined along a transect from the southwest corner to the northeast corner of the nearfield area (see Figure 1-3). The southwest corner, station N10, often exhibits a harbor chlorophyll signal while an offshore chlorophyll signal is more often observed at the northeast corner, station N04. Chlorophyll concentrations were relatively low (<3 μgL^{-1}) during the first two surveys of 2000 (Figure 4-39). The highest chlorophyll concentrations of this semiannual period were observed during the March survey (WN003). By March, surface chlorophyll concentrations had increased to 7-11 μgL^{-1} at inshore stations (N10 and N19) and to 3-9 μgL^{-1} along the rest of the nearfield transect. A subsurface chlorophyll maximum (>9 μgL^{-1}) was present along the whole nearfield transect except at station N10. The highest concentrations (>13 μgL^{-1}) were at 5-10 m depths in the middle of the nearfield (stations N21 and N15). Phytoplankton data collected from stations N14 and N18 indicate that total abundance and the abundance (and dominance) of *Phaeocystis* and centric diatoms increased from February to March resulting in a concurrent increase in chlorophyll. The surface and mid-depth phytoplankton abundances were similar in March so it is likely that the elevated chlorophyll concentrations at depth were due to an increase in chlorophyll per cell in response to decreasing light at depth in the well-mixed water column.

In April (WF004), chlorophyll concentrations had decreased from the March levels, but concentrations at the subsurface maximum were still >9 μgL^{-1} across most of the nearfield transect (Figure 4-39c). Surface chlorophyll concentrations were highest at station N10 (>5 μgL^{-1}) and decreased sharply to <1 μgL^{-1} at station N21 and the eastern nearfield. This was coincident with a very strong inshore to offshore decrease in nutrient concentrations. The availability of nutrients at depth led to the subsurface chlorophyll maximum that was located just above the pycnocline (~20 m). Phytoplankton abundances in the nearfield chlorophyll maximum samples were almost double that of the surface samples (3-6 million cells L^{-1} versus 7-11 million cells L^{-1}). The elevated chlorophyll concentrations and phytoplankton abundance were concomitant with high production rates during the April survey. Production peaked in March at station N18 (although still high in April) and in April at the more offshore station N04. In comparison to the March survey, the chlorophyll per cell ratio was much lower in April and with the inshore to offshore trends in production may suggest that the survey was conducted towards the end of the *Phaeocystis* bloom.

By early May, chlorophyll concentrations had decreased to <4 μgL^{-1} over all of the nearfield transect. There was an equally severe decrease observed in phytoplankton abundance from 4-11 million cells L^{-1} in early April to ≤1 million cells L^{-1} in early May. By mid-May, the surface chlorophyll concentrations at the harbor-influenced western nearfield stations had increased to >13 μgL^{-1} and there was a gradient of decreasing surface concentrations further offshore (Figure 4-40). The maximum chlorophyll concentrations were at that surface in the western nearfield and subsurface at the offshore stations. The increase in chlorophyll was coincident with an increase in phytoplankton from early to mid-May. A similar pattern and range of chlorophyll concentrations was observed during the June survey (WF007). The main difference was a shallower surface layer at the inshore stations and that the offshore subsurface chlorophyll maximum occurred over a narrower depth interval. By July, the typical summer chlorophyll pattern was observed in the nearfield. Elevated chlorophyll concentrations at the harbor-influenced western nearfield stations and a deepening subsurface chlorophyll maximum across the rest of the nearfield, which is associated with the pycnocline and the nutrients available from the deeper waters.

4.2.3 Dissolved Oxygen

Spatial and temporal trends in the concentration of dissolved oxygen (DO) were evaluated for the entire region (Section 4.2.3.1) and for the nearfield area (Section 4.2.3.2). Due to the relative importance of identifying low DO conditions, bottom water DO minima were examined for the water sampling events. The minimum measured DO concentration was 7.88 mgL^{-1} in the nearfield in July (WN009). Regionally, a DO concentration minimum of 8.00 mgL^{-1} was observed in Boston Harbor in June (WF007). DO concentrations were within the range of values observed during previous years. The June bottom water DO concentration has traditionally been used as an indicator of DO minimum concentrations in September/October. This early warning indicator could be used to alleviate or at least heighten awareness about potentially harmful bottom water DO conditions that could occur in the fall. The June bottom water concentrations in 2000 were slightly higher (~0.5 mgL^{-1}) in each of the regional areas than the values measured in 1999, which ended up having the lowest fall DO minima of the entire baseline period. Although there was an extraordinary *Phaeocystis* bloom in 2000, physical factors likely led to a delay in establishment of stratified conditions and continued ventilation of the bottom waters through June. This biological and physical factors that affect bottom water DO concentrations in Massachusetts Bay will be evaluated in more detail in the 2000 Nutrient Issues Review.

4.2.3.1 Regional Trends of Dissolved Oxygen

The DO of bottom waters was compared between areas and over the course of the four combined surveys. A time series of the average bottom water DO concentration for each area is presented in Figure 4-41a. Average bottom water DO concentrations ranged from 8 to 13 mgL^{-1}. Bottom water DO concentrations remained relatively constant from early February through April for most of the bays. Lower concentrations were consistently observed at the deeper boundary and offshore areas over this period. In Cape Cod Bay, bottom water DO concentrations decreased by almost 2 mgL^{-1} from late February to early April. This was likely related to the decline of the centric diatom bloom that was suggested by phytoplankton data at the Cape Cod Bay stations in late February (see Figure 5-17). Between the April and June surveys, there was a sharp decline in bottom water DO throughout the bays. In Boston Harbor, bottom water DO concentrations declined by ~3 mgL^{-1}. Declines of 1-2 mgL^{-1} were found in the other areas. The trend of declining bottom water DO concentrations following the establishment of stratification and the cessation of the winter/spring bloom is typical for the bays. The decline observed in 2000 was less than that seen during 1999 and may be an indication that bottom water DO concentrations may not achieve the very low levels seen in the fall of 1999.

The trend of decreasing DO in the bottom waters was less apparent in the DO %saturation data (Figure 4-41b). In general, DO %saturation decreased in each of the areas from early February to June, but there were no consistent trends from survey to survey across the region. Boston Harbor bottom water DO %saturation increased from late February to April, while coastal, offshore and boundary values remained relatively stable, and Cape Cod Bay DO %saturation declined. Bottom waters were supersaturated during this time period in the Boston Harbor and the coastal areas and slightly undersaturated in the deep waters of the boundary and offshore areas. In June, bottom waters were undersaturated with respect to DO in all of the areas except coastal waters with average values ranging from about 90% to 98% saturation.

In February, the spatial distribution of DO generally exhibited an inshore to offshore trend of decreasing DO concentrations along three regional transects and there was more variability over depth along the Marshfield transect and along all three transects in late February. By April, the winter/spring bloom led to high DO concentrations in the surface layer and DO concentrations had decreased slightly in the bottom waters along each of the transects, but all bottom water values were

still >9 mgL^{-1} (Figure 4-42). In June, DO concentrations had decreased from the April values throughout the water column and reached relatively low levels (8-9 mgL^{-1}) in the harbor and in coastal and some offshore bottom waters. In Figure 4-43, bottom water DO concentrations are presented over the entire region for the June survey. Low DO concentrations (<9 mgL^{-1}) were located in three areas: Boston Harbor, Cape Cod Bay and an area stretching from the eastern nearfield south to the coast off of Marshfield, MA.

4.2.3.2 Nearfield Trends of Dissolved Oxygen

Dissolved oxygen concentrations and percent saturation values for both the surface and bottom waters of the 21 nearfield stations were averaged and plotted for each of the nearfield surveys. From February to April, the average surface water DO concentrations for the nearfield area increased from ~10.5 to almost 13 mgL^{-1} (Figure 4-44a). The maximum concentration of almost 13 mgL^{-1} observed in April was coincident with elevated chlorophyll concentrations and high primary production. Following the April survey, surface water DO concentrations decreased reaching average concentrations of about 10±0.5 mgL^{-1} in June and July. Bottom water DO concentrations remained stable (~10.5 mgL^{-1}) from early February through April and then decreased from April to July reaching concentrations of <9 mgL^{-1} in July.

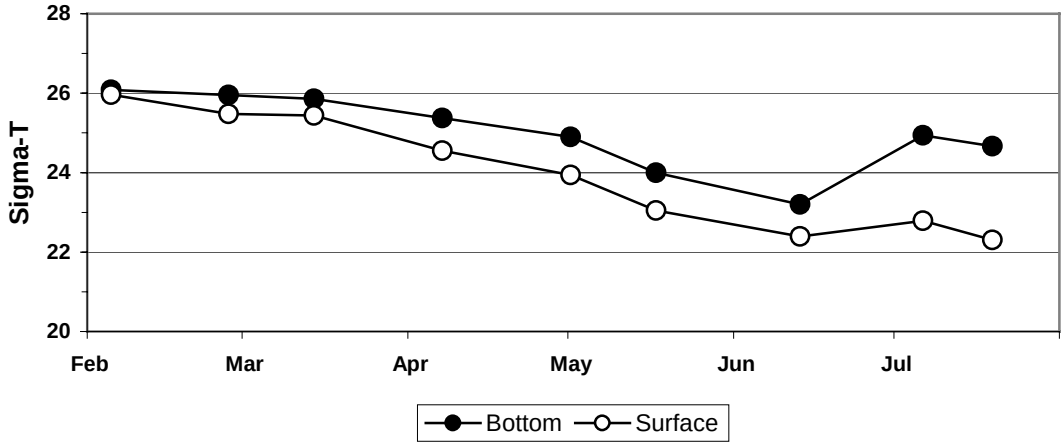
The average DO %saturation for the surface waters followed the same increasing trend as DO concentration from early February to April (Figure 4-44b). The surface waters were slightly under saturated with respect to DO in early February (~95%) and increased steadily until reaching supersaturated levels in April (~125%). Surface water DO %saturation varied by 10-15% from April to July, but remained supersaturated at levels of 110-130% for the rest of the time period. There was little variation in average DO %saturation for the bottom waters for the first five surveys of 2000 ranging from 95 to 100 %saturation. As the water column began to stratify in May (WN006), bottom water DO %saturation began to decrease, but values increased again in June to >100% saturation following the storm induced mixing events. Following the June survey, DO %saturation values decreased to ~90 %saturation in July.

In February and March, the water column was well mixed and DO concentrations were relatively consistent across the nearfield with slightly higher values in the surface waters. By April, large vertical gradients in DO concentration were observed because of a combination of biological factors (Figure 4-45). In the surface water, the increase in DO concentrations was concomitant with an increase in chlorophyll concentrations, phytoplankton abundance and production rates. DO concentrations remained relatively unchanged in the bottom waters. By mid-May, the water column had begun to stratify and bottom water DO concentrations had decreased to <10 mgL^{-1} and to <9 mgL^{-1} at offshore stations. The storm mixing events in June homogenized the water column with respect to DO concentrations and values of 9-10 mgL^{-1} were observed over the entire nearfield transect. By July, the nearfield water column had become strongly stratified. DO concentrations increased from June values in the surface waters and in the subsurface chlorophyll maximum layer while in the bottom waters respiration rates had increased and reduced DO concentrations to less than 9 mgL^{-1} across the entire transect.

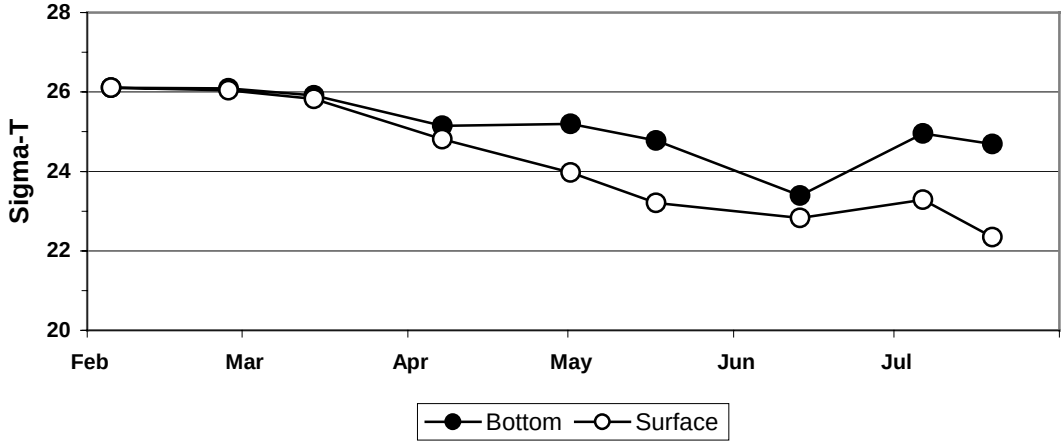
4.3 Summary of Water Column Results

- The onset of stratification was observed during the April combined survey in Boston Harbor and at the deep boundary stations. The development of stratification at these stations was primarily driven by a decrease in surface salinity, as surface and bottom water temperatures remained relatively unchanged. By June, surface water temperatures had increased by ~7°C throughout the bays and a strong density gradient was observed at the offshore and boundary stations. Due to storm events and associated mixing, stratification was still weak at the shallower coastal, Cape Cod Bay, and Boston Harbor stations. Boston Harbor usually remains well mixed due to tidal flushing.
- In the nearfield, the water column had begun to stratify in early May at the deeper eastern nearfield stations. The storm events in June remixed the water column and contributed to the relatively weak stratification that was observed. By July a strong density gradient was observed and stratified conditions had become established in the nearfield.
- The nutrient data for February to July 2000 generally followed the "typical" progress of seasonal events in the Massachusetts and Cape Cod Bays.
  - Maximum nutrient concentrations were observed in early February when the water column was well mixed and biological uptake of nutrients was limited.
  - The winter/spring *Phaeocystis* bloom reduced nutrient concentrations in the surface waters from March to April. NO_3 and PO_4 concentrations in the surface waters were depleted throughout much of the region.
  - Seasonal stratification led to persistent nutrient depleted conditions in the surface waters and ultimately to an increase in nutrient concentrations in bottom waters due to increased rates of remineralization of organic matter.
- The harbor signal of elevated nutrient concentrations (especially ammonium) was observed throughout this time period, although harbor nutrient concentrations were reduced substantially during the *Phaeocystis* bloom.
- The mean chlorophyll concentration for the nearfield for winter/spring 2000 was higher than any previous winter/spring mean obtained during the baseline monitoring period and exceeded the provisional chlorophyll threshold value that had been calculated as two times the baseline mean for 1992 to 1998.
- The unprecedented nearfield winter/spring chlorophyll concentrations were directly reflected in the phytoplankton abundance data. *Phaeocystis* counts reached levels of >10 million cells L^{-1} in the nearfield.
- DO concentrations in 2000 were within the range of values observed during previous years and followed the typical trends:
  - In February, the water column was well mixed and DO concentrations were high and consistent across the region.
  - By April, vertical gradients in DO concentration were observed because productivity was high in the surface waters, and the increases in chlorophyll concentrations, phytoplankton abundance and production rates led to increased DO concentrations.
  - The storm events in June served to mix the water column to some degree increasing bottom water DO concentrations from the levels observed in May
  - In July, the nearfield water column had become strongly stratified.
    - DO concentrations remained high in the surface waters and in the subsurface chlorophyll maximum layer.
    - In the bottom waters, increased respiration rates reduced DO concentrations to less than 9 mgL^{-1} at some stations.

(a) Inner Nearfield: N10, N11



(b) Broad Sound: N01



(c) Outer Nearfield: N04, N07, N16, N20

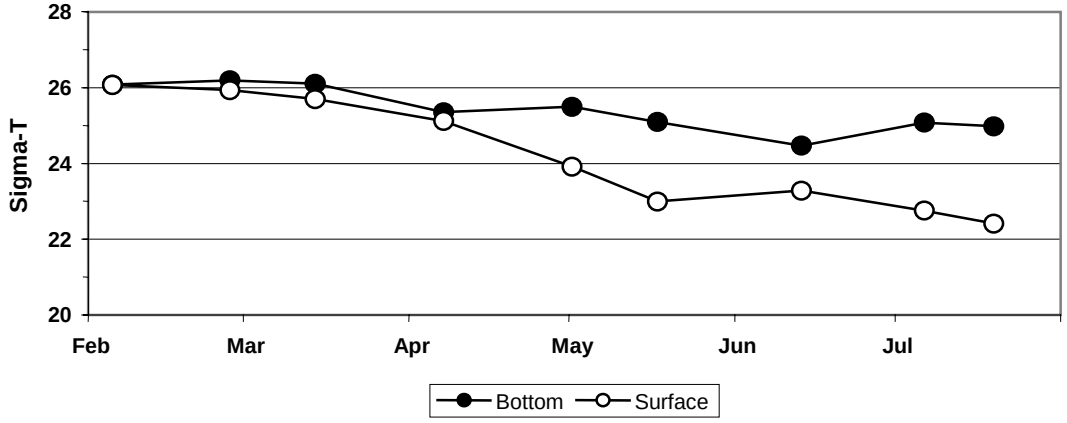


Figure 4-1. Time-Series of Average Surface and Bottom Water Density (σ_t) in the Nearfield

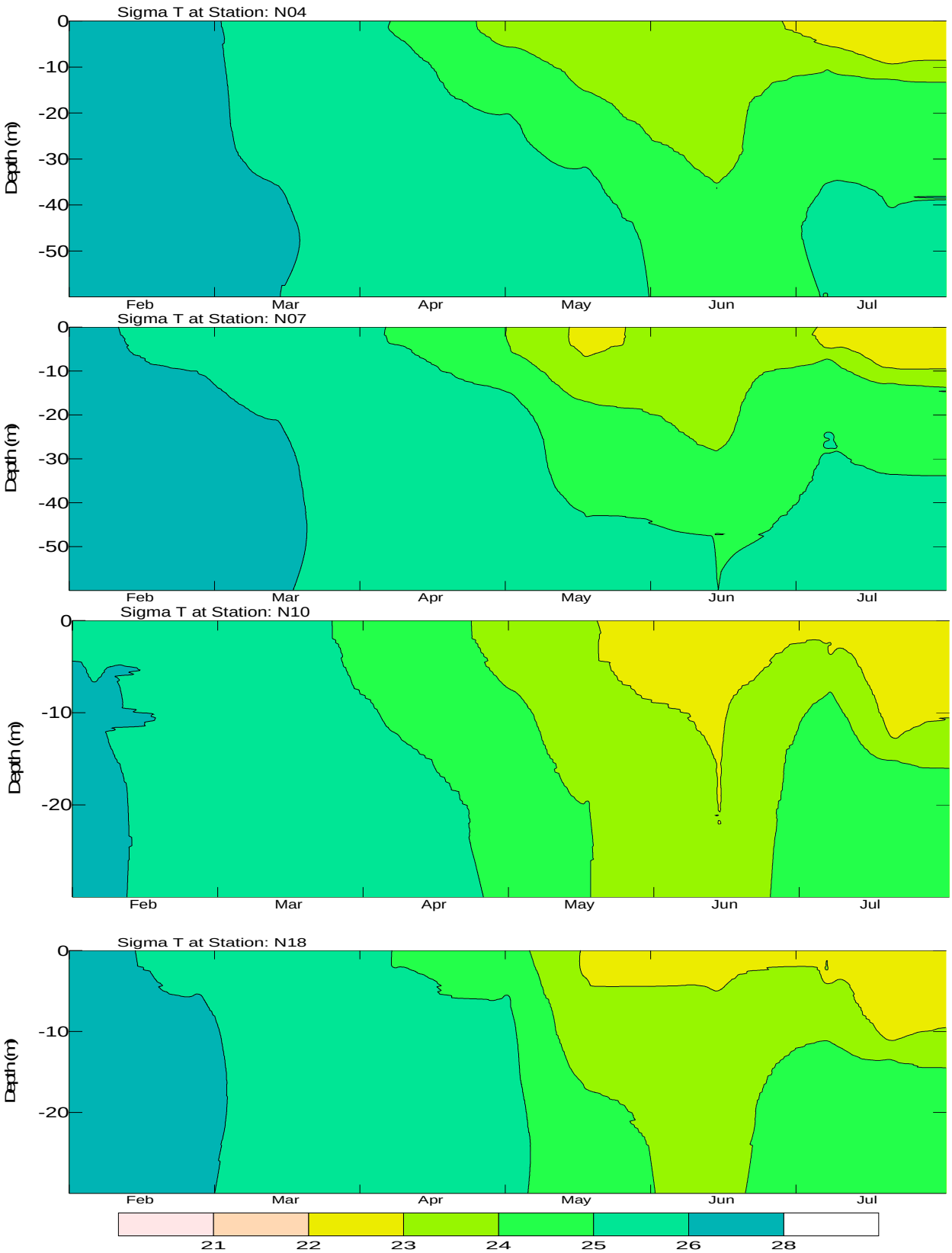


Figure 4-2. Nearfield Depth vs. Time Contour Plots of Sigma-T for Stations N04, N07, N10 and N18

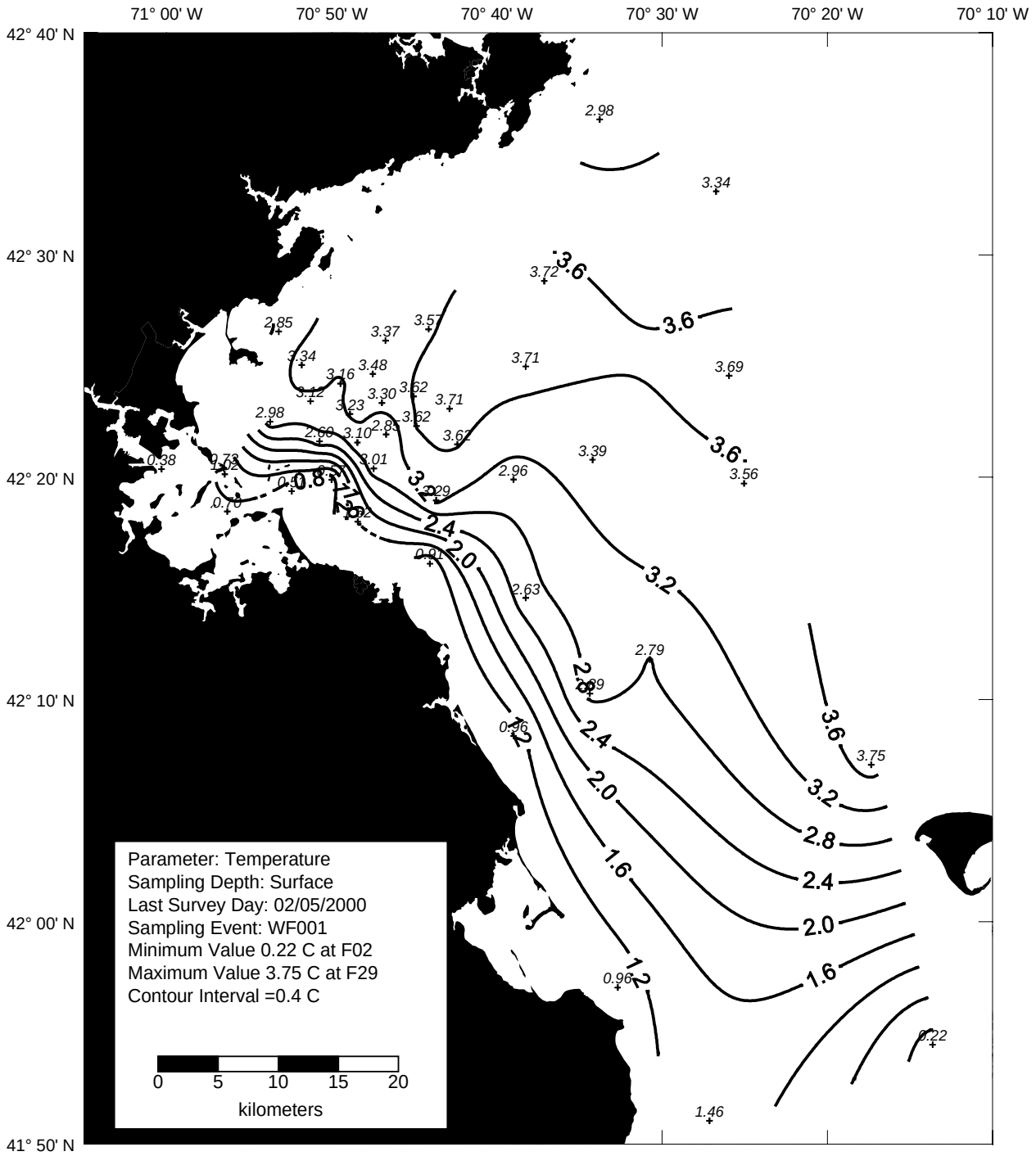


Figure 4-3. Temperature Surface Contour Plot for Farfield Survey WF001 (Feb 00)

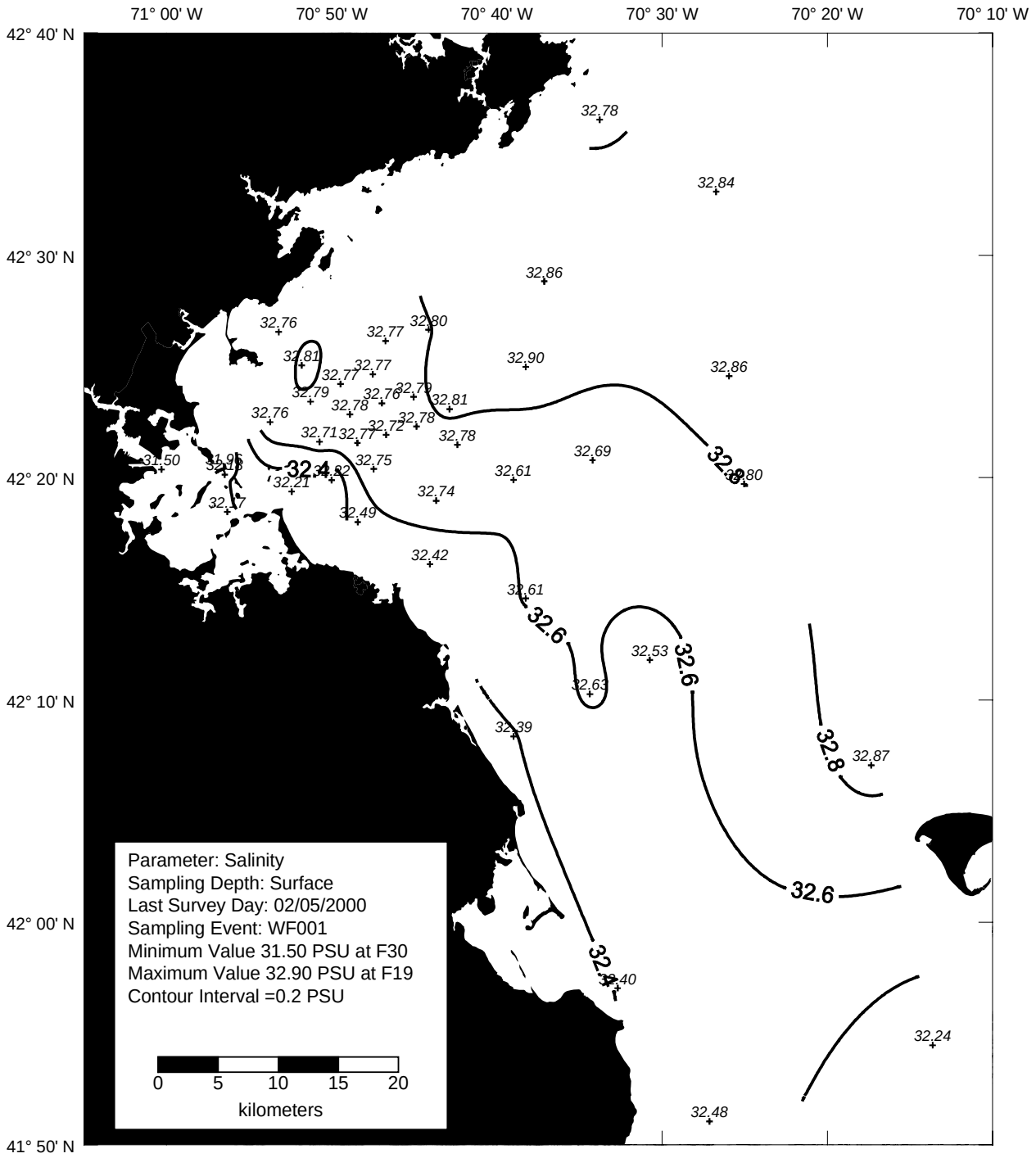


Figure 4-4. Salinity Surface Contour Plot for Farfield Survey WF001 (Feb 00)

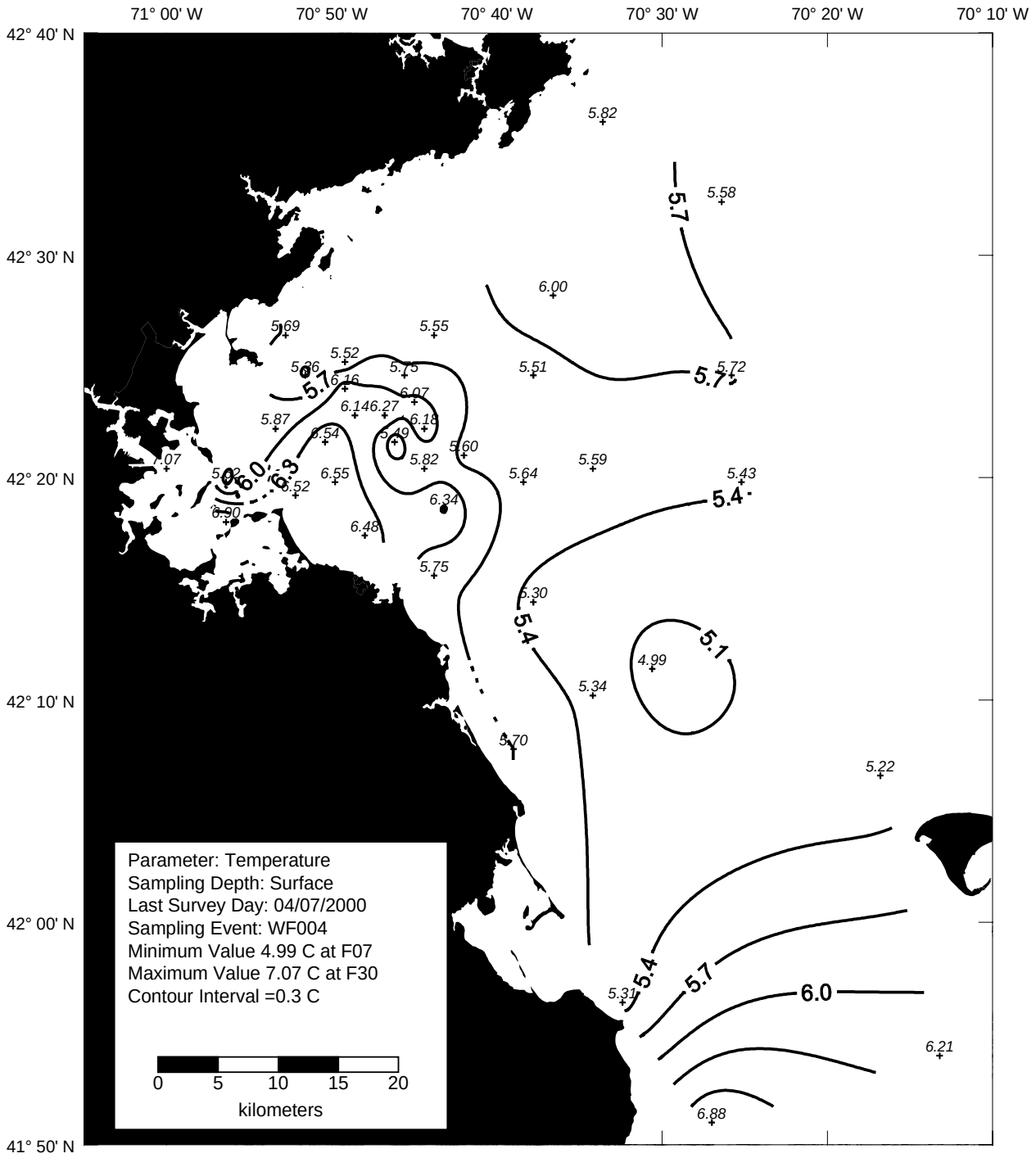


Figure 4-5. Temperature Surface Contour Plot for Farfield Survey WF004 (Apr 00)

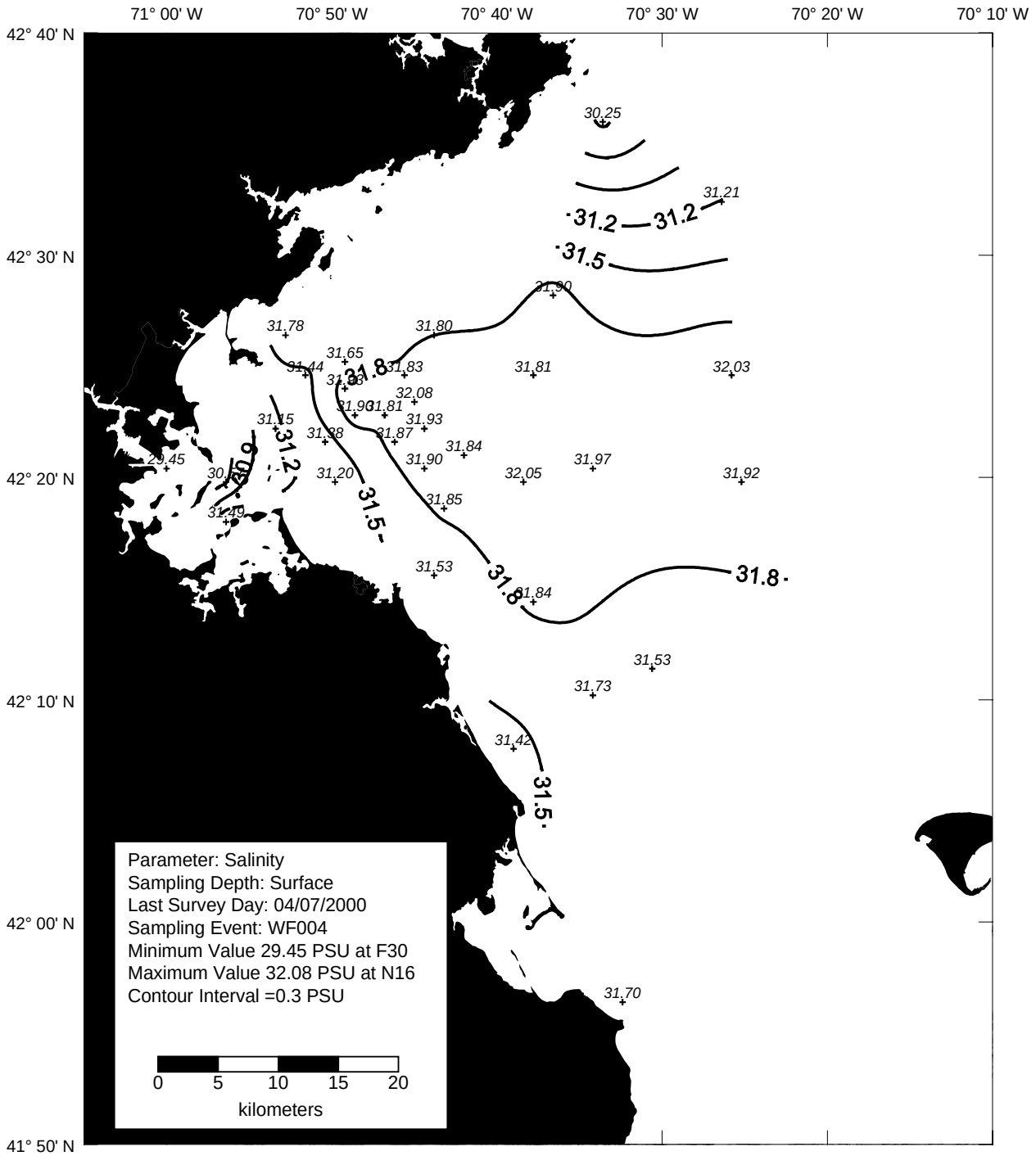


Figure 4-6. Salinity Surface Contour Plot for Farfield Survey WF004 (Apr 00)

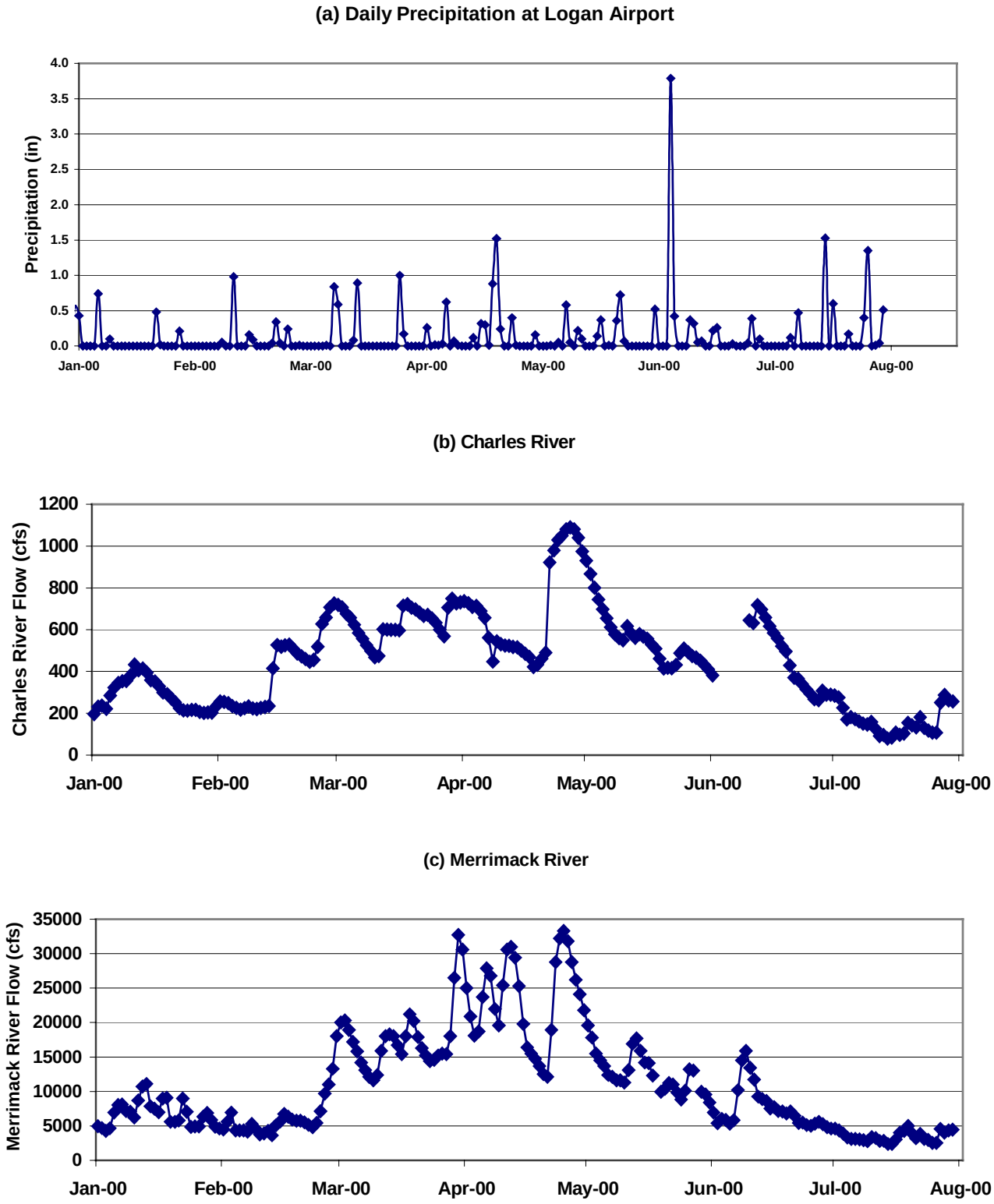


Figure 4-7. Precipitation at Logan Airport and River Discharges for the Charles and Merrimack Rivers

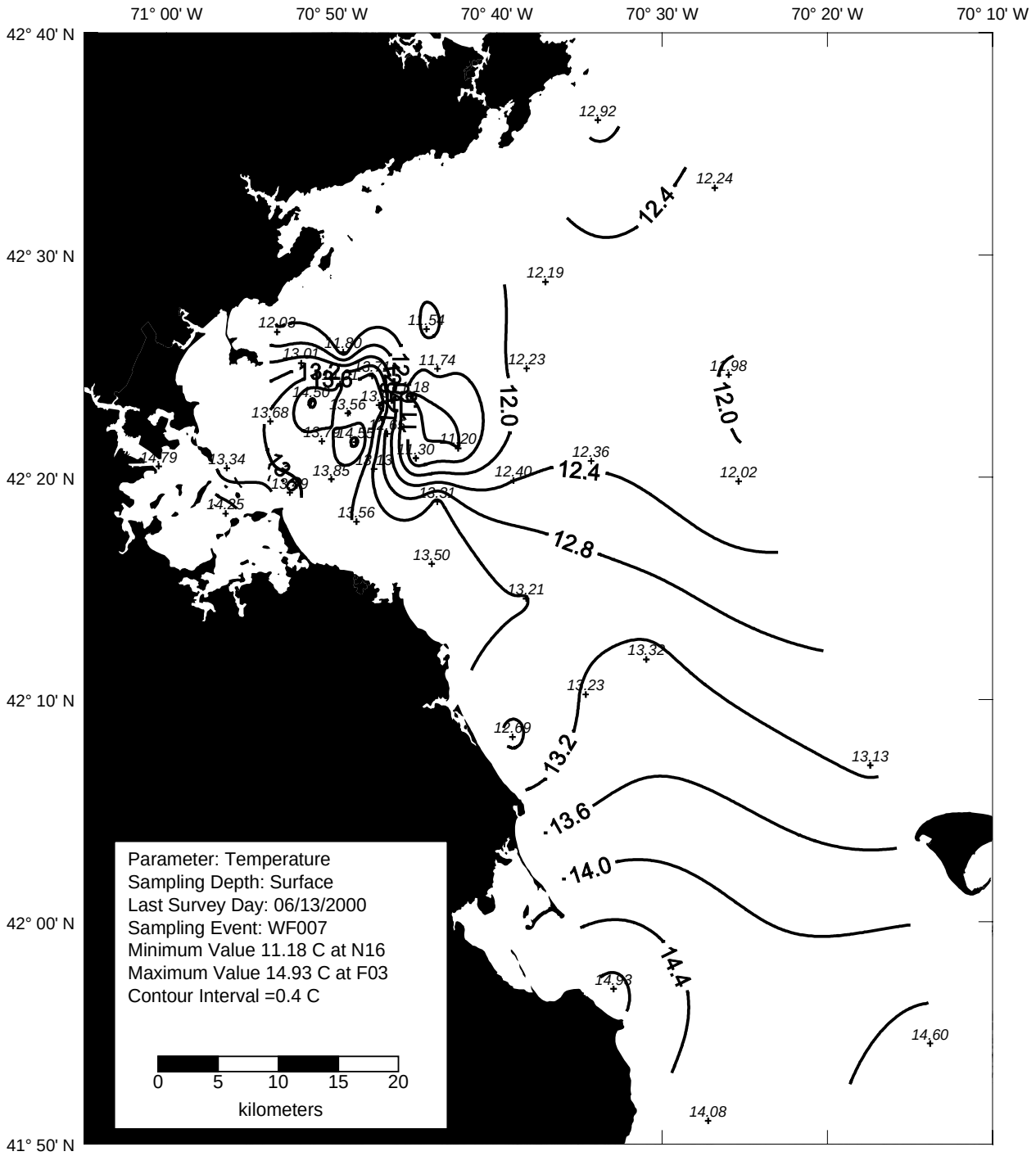


Figure 4-8. Temperature Surface Contour Plot for Farfield Survey WF007 (Jun 00)

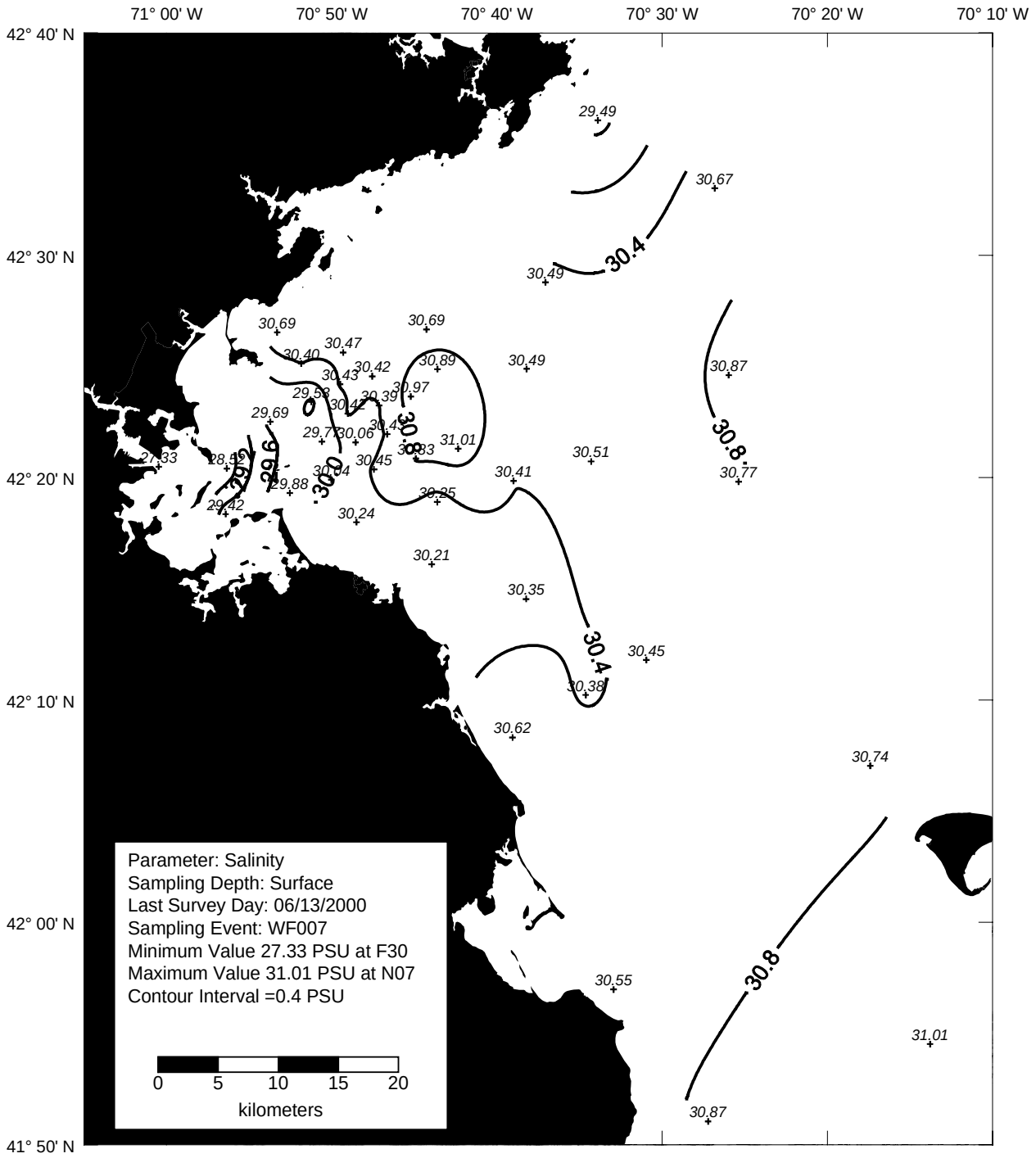
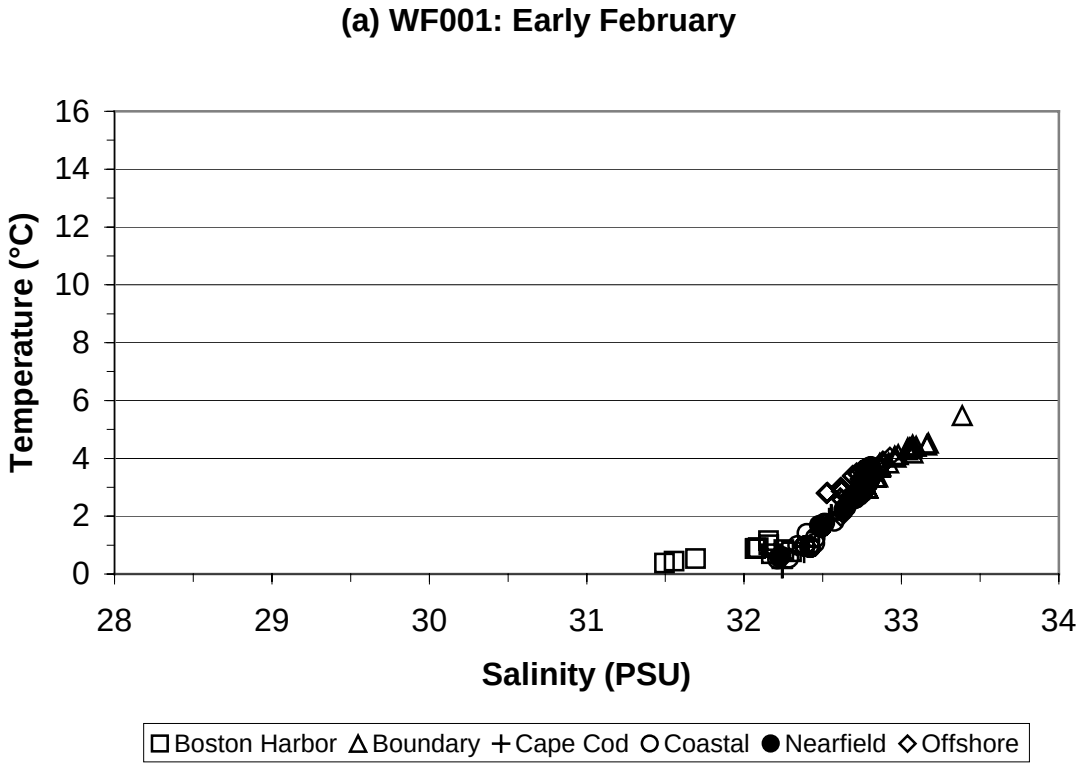


Figure 4-9. Salinity Surface Contour Plot for Farfield Survey WF007 (Jun 00)



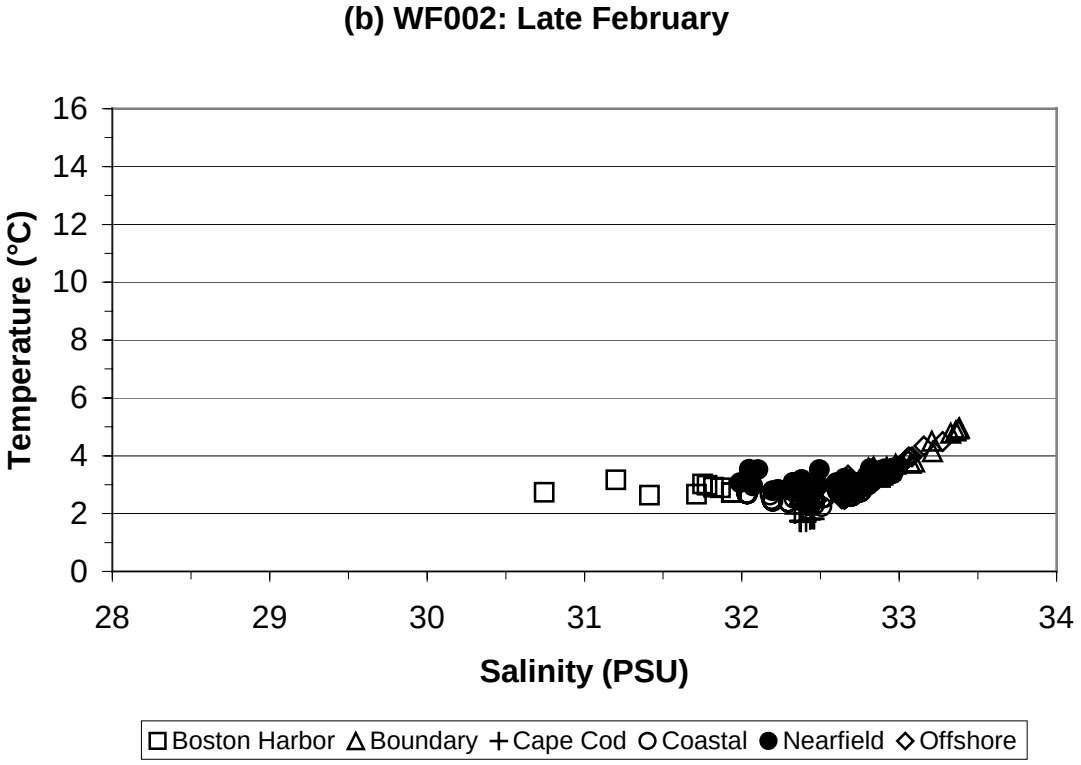
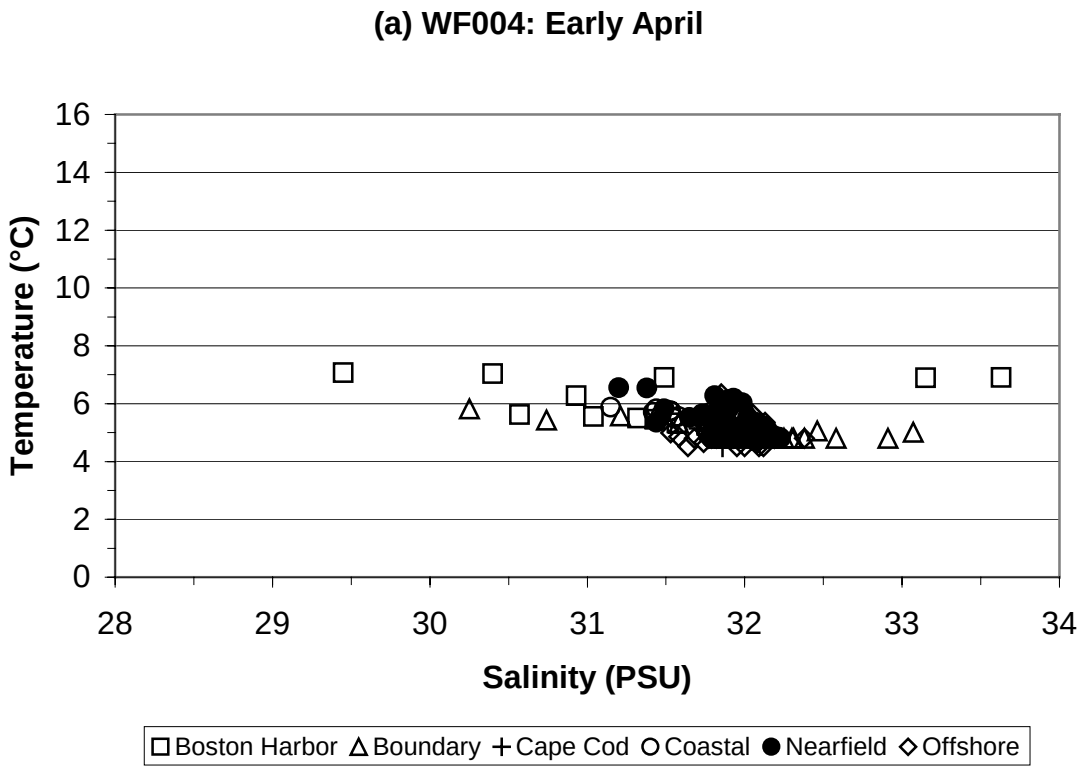


Figure 4-10. Temperature/Salinity Distribution for All Depths during WF001 (Feb 00) and WF002 (Feb 00) Surveys



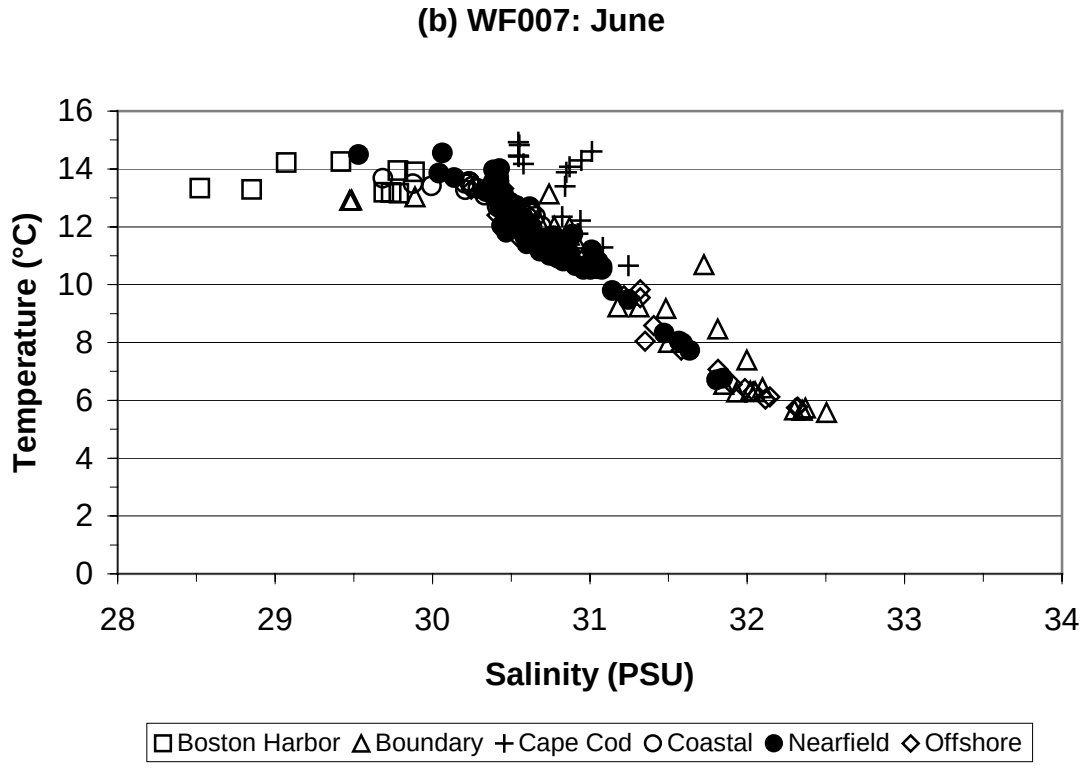


Figure 4-11. Temperature/Salinity Distribution for All Depths during WF004 (Apr 00) and WF007 (Jun 00) Surveys

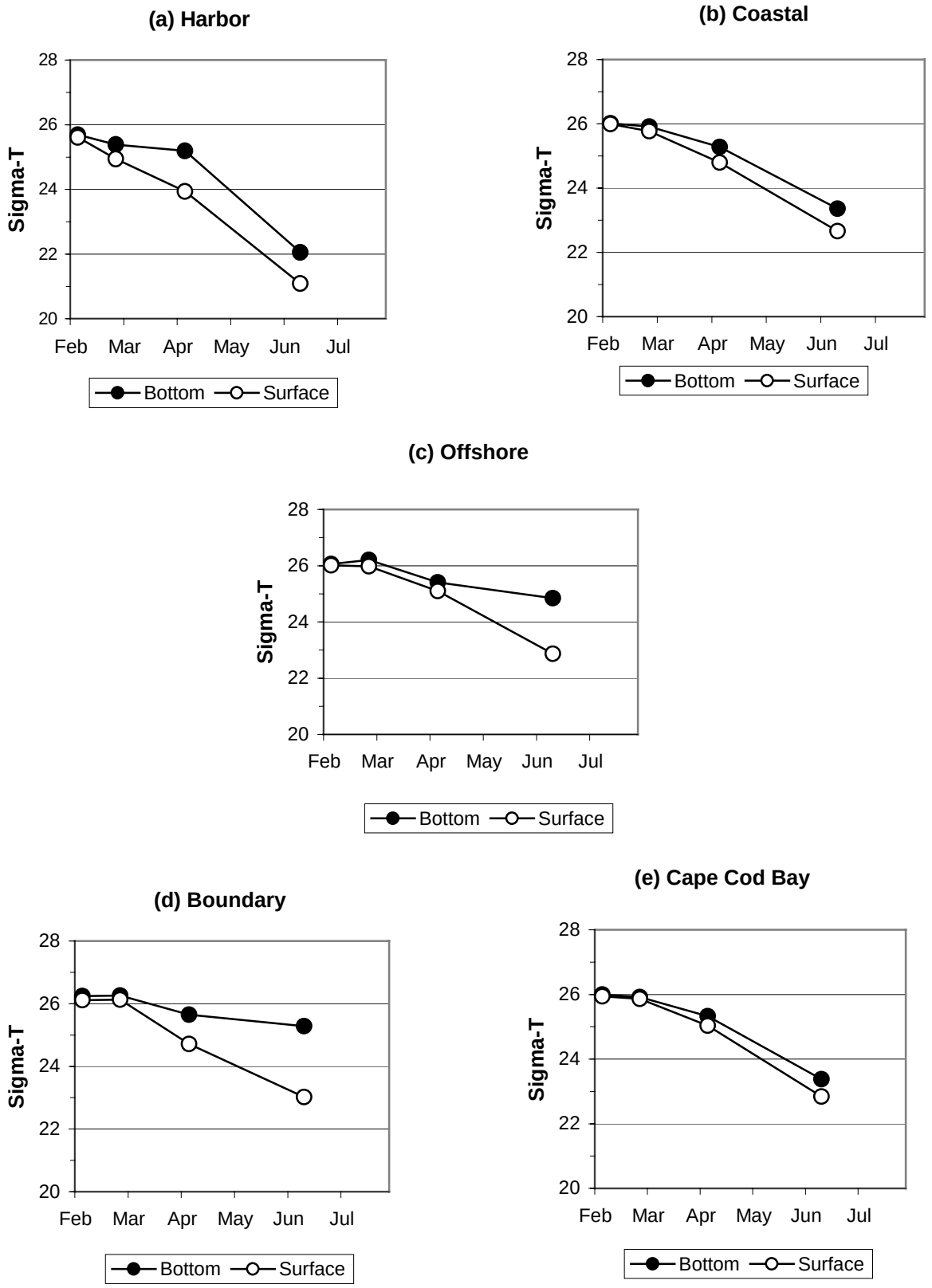


Figure 4-12. Time-Series of Average Surface and Bottom Water Density (σ_T) in the Farfield

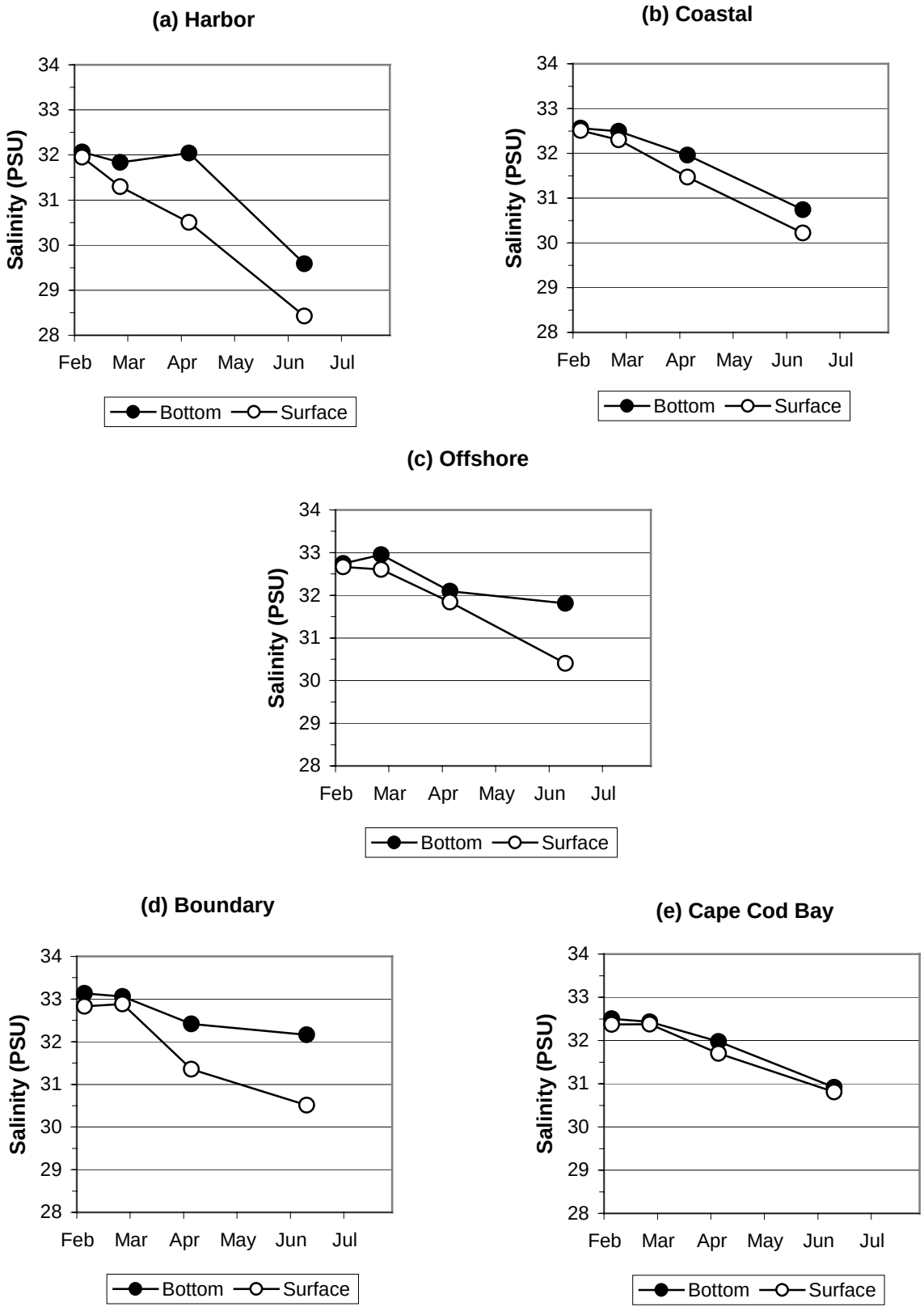


Figure 4-13. Time-Series of Average Surface and Bottom Water Salinity (PSU) in the Farfield

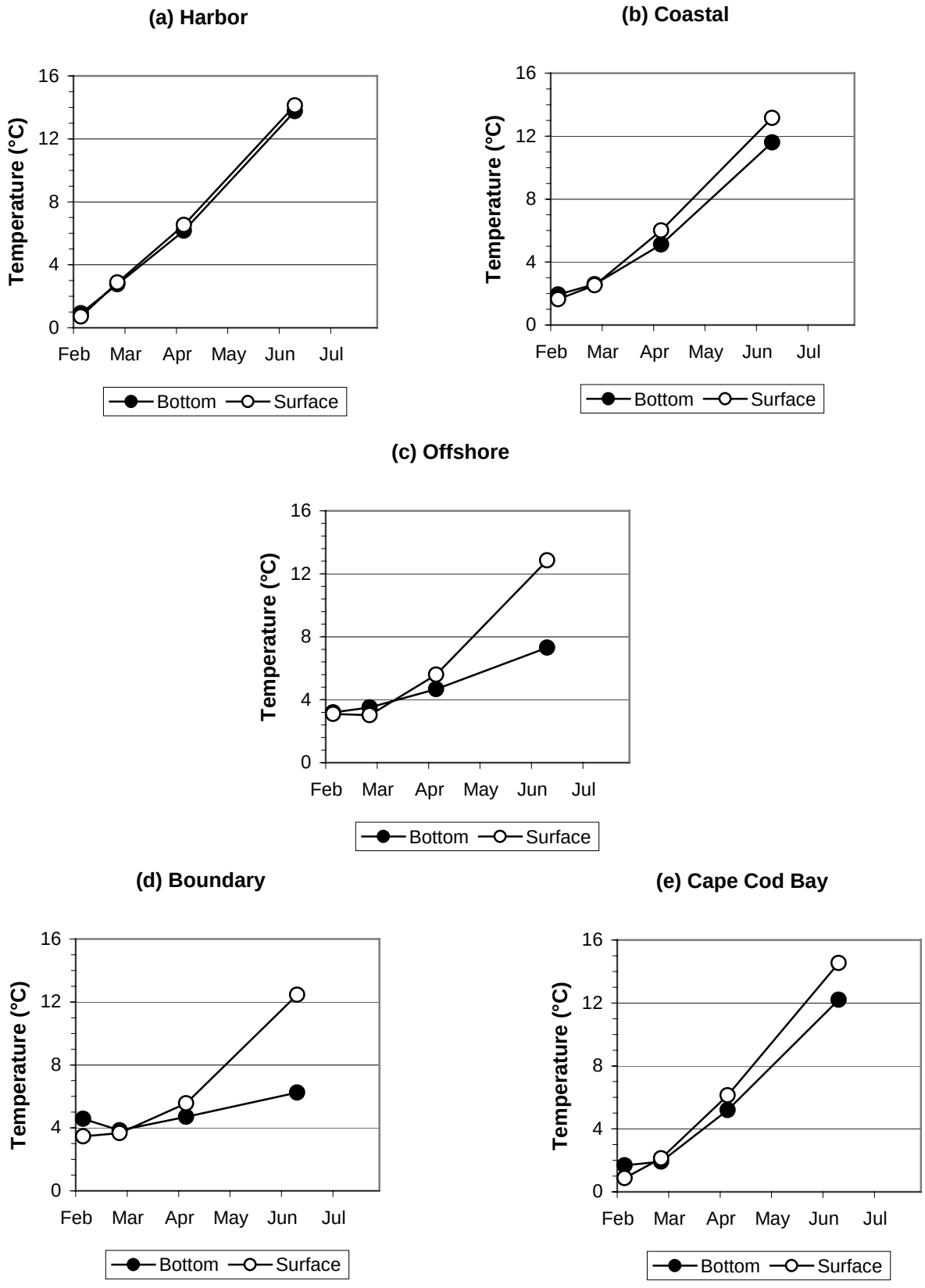


Figure 4-14. Time-Series of Average Surface and Bottom Temperature (°C) in the Farfield

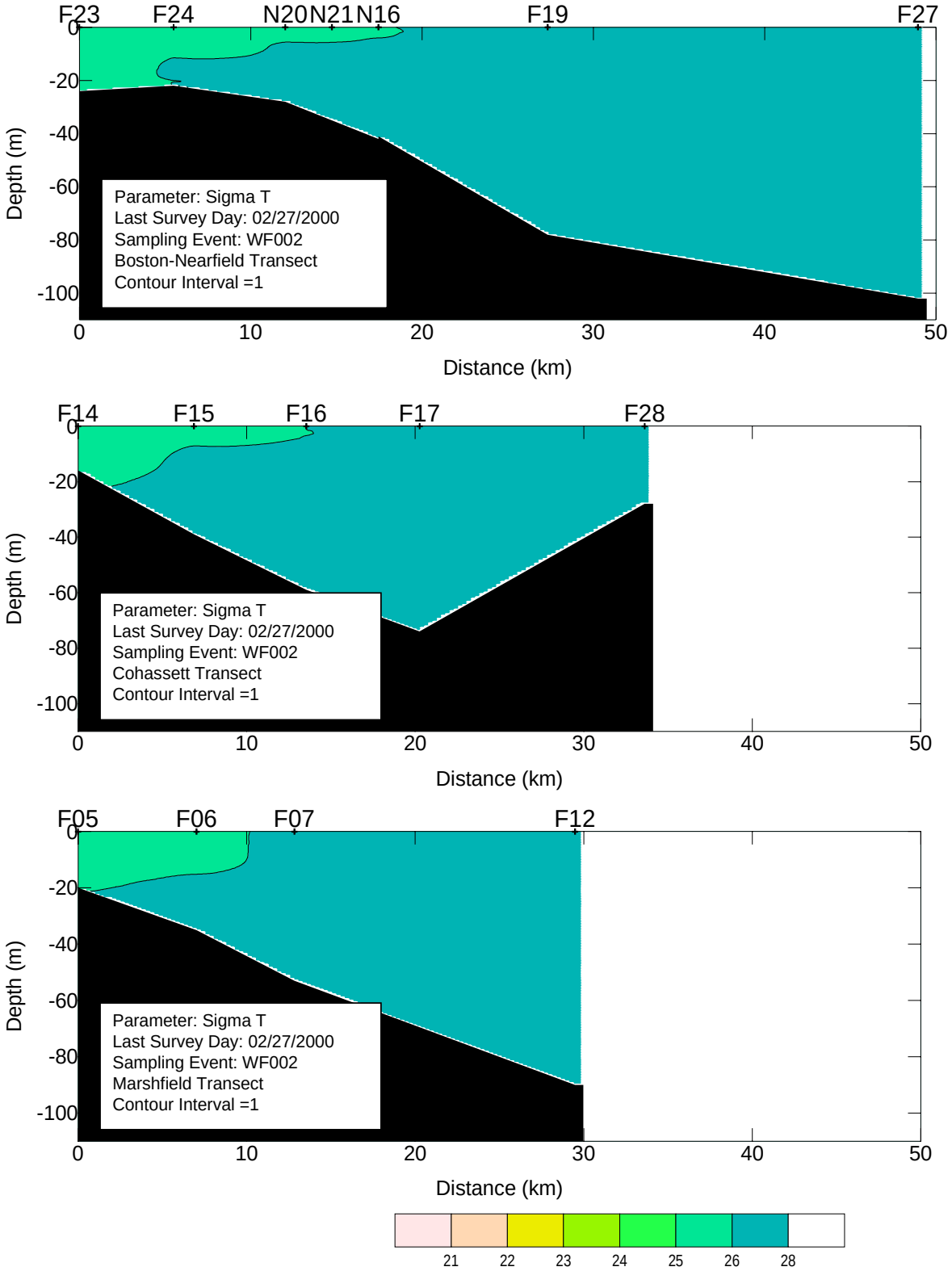


Figure 4-15. Sigma-T Vertical Transects for Farfield Survey WF002 (Feb 00)

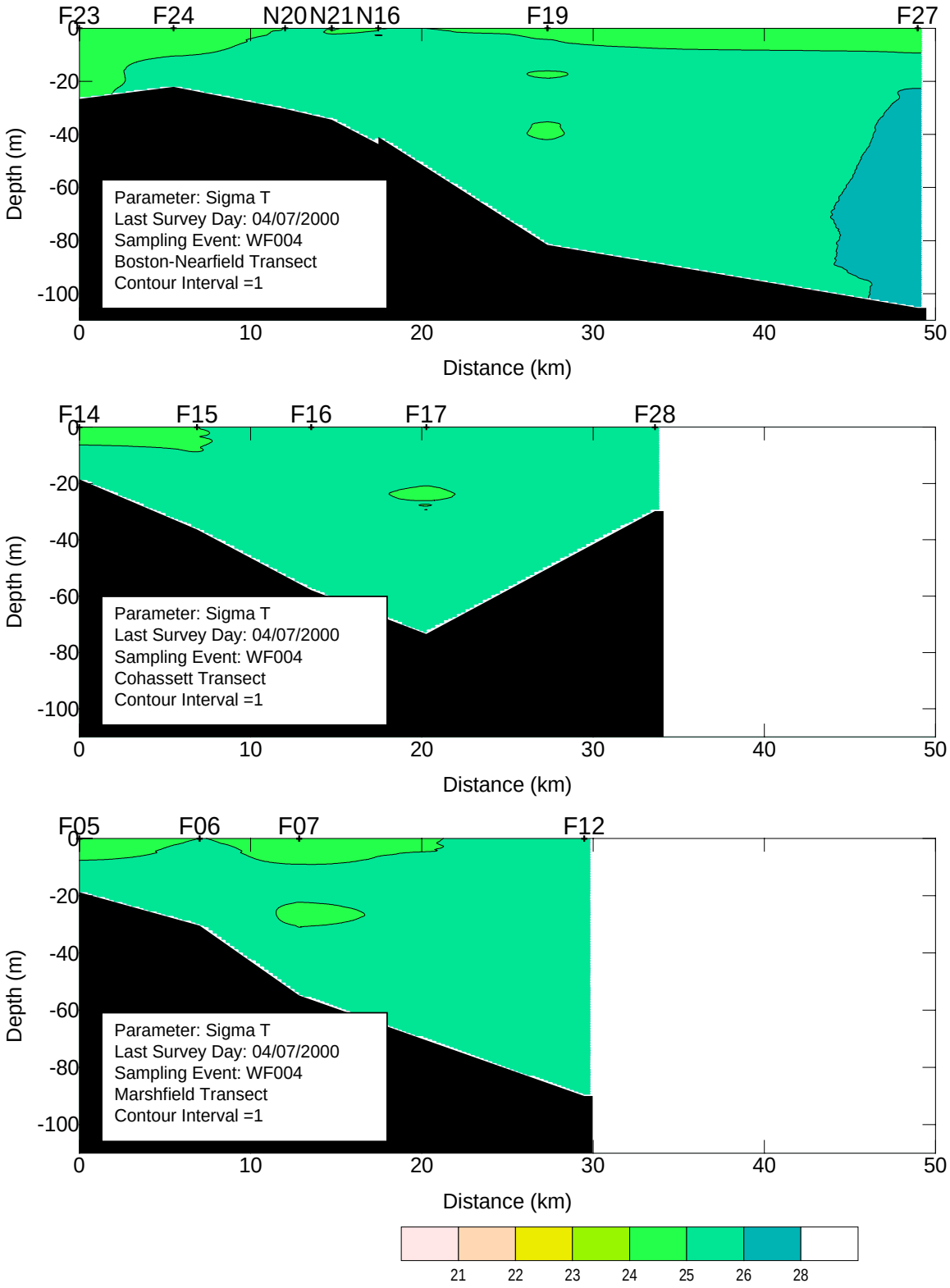


Figure 4-16. Sigma-T Vertical Transect for Farfield Survey WF004 (Apr 00)

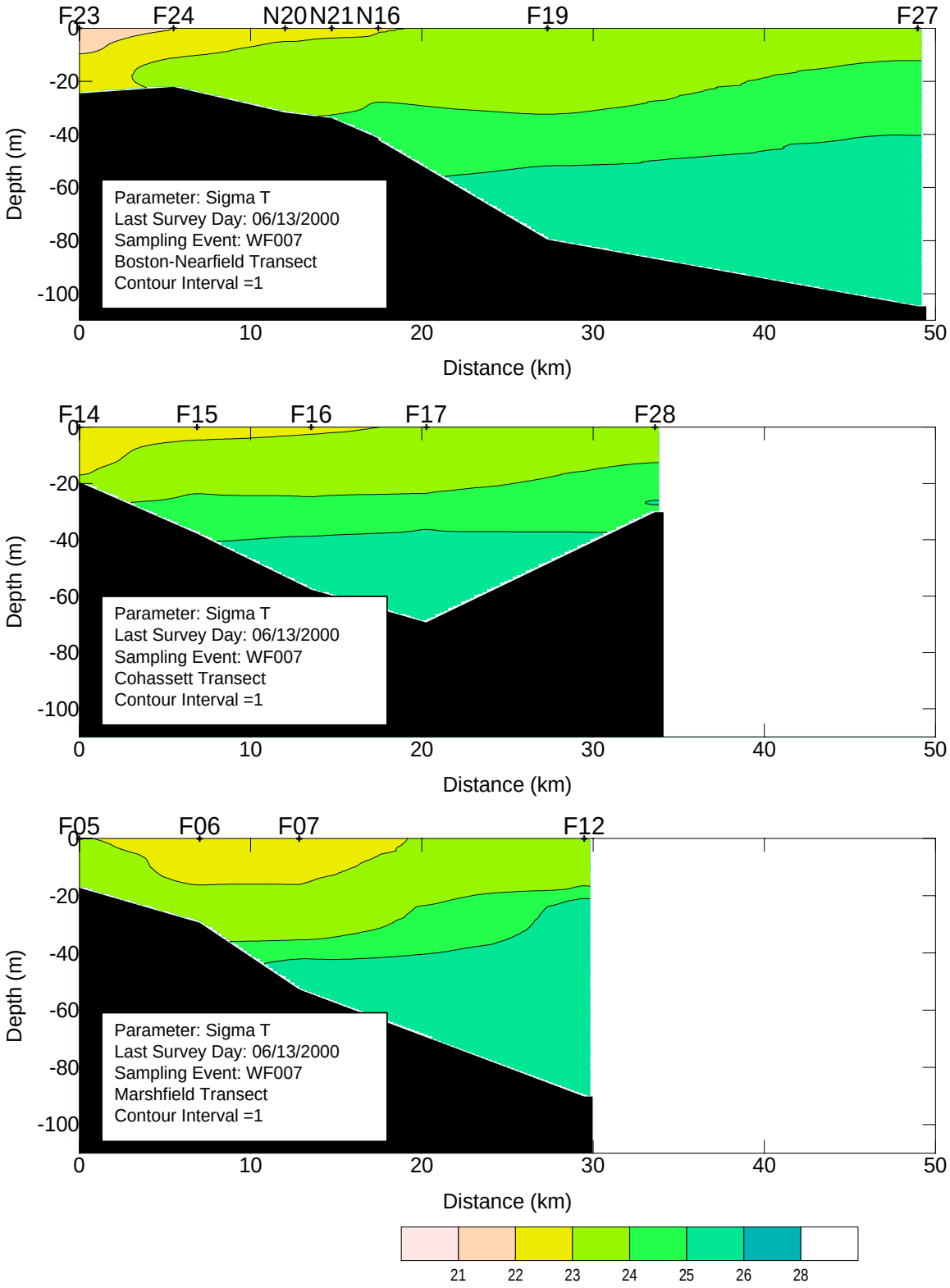


Figure 4-17. Sigma-T Vertical Transect for Farfield Survey WF007 (Jun 00)

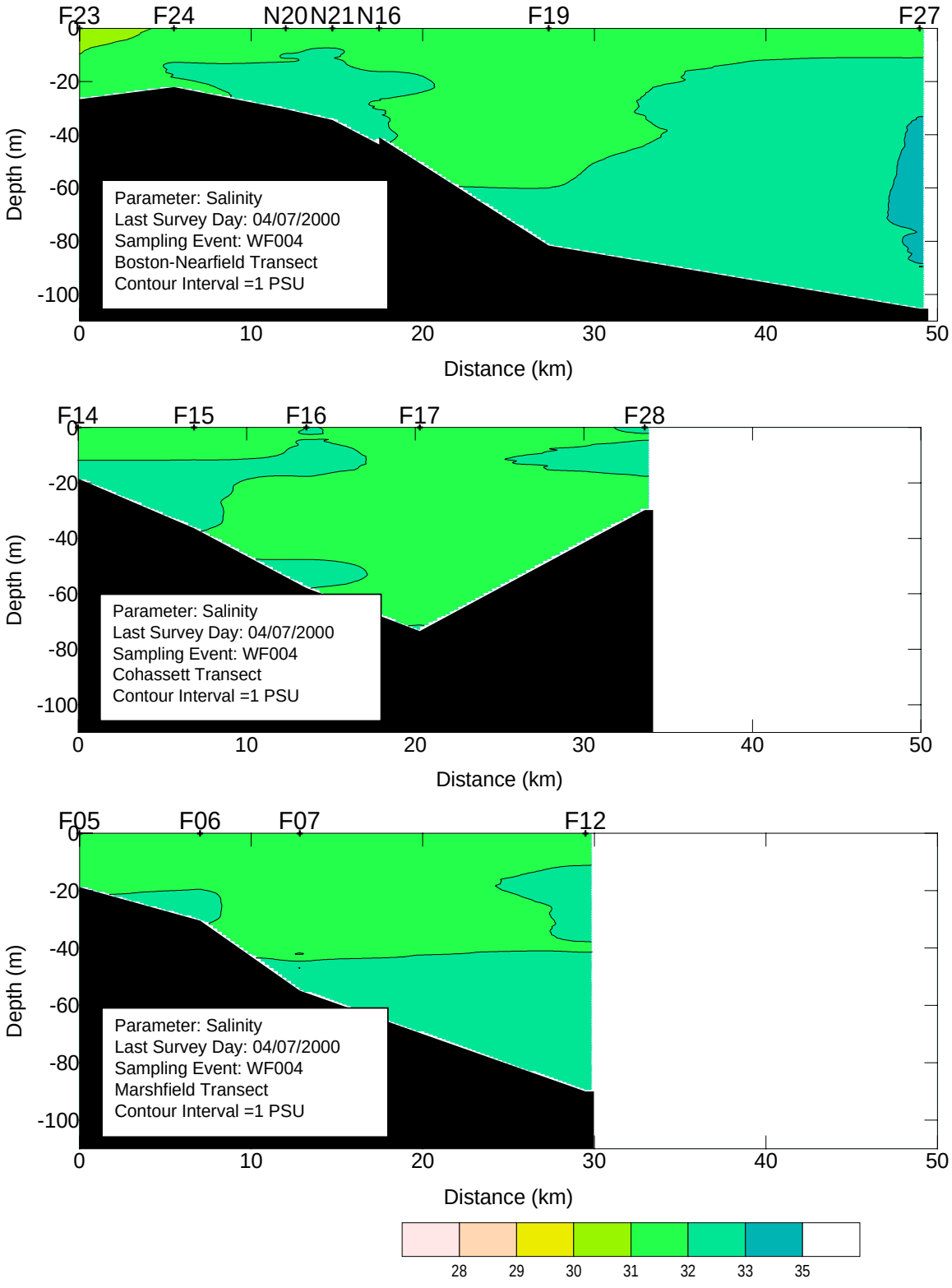


Figure 4-18. Salinity Vertical Transect for Farfield Survey WF004 (Apr 00)

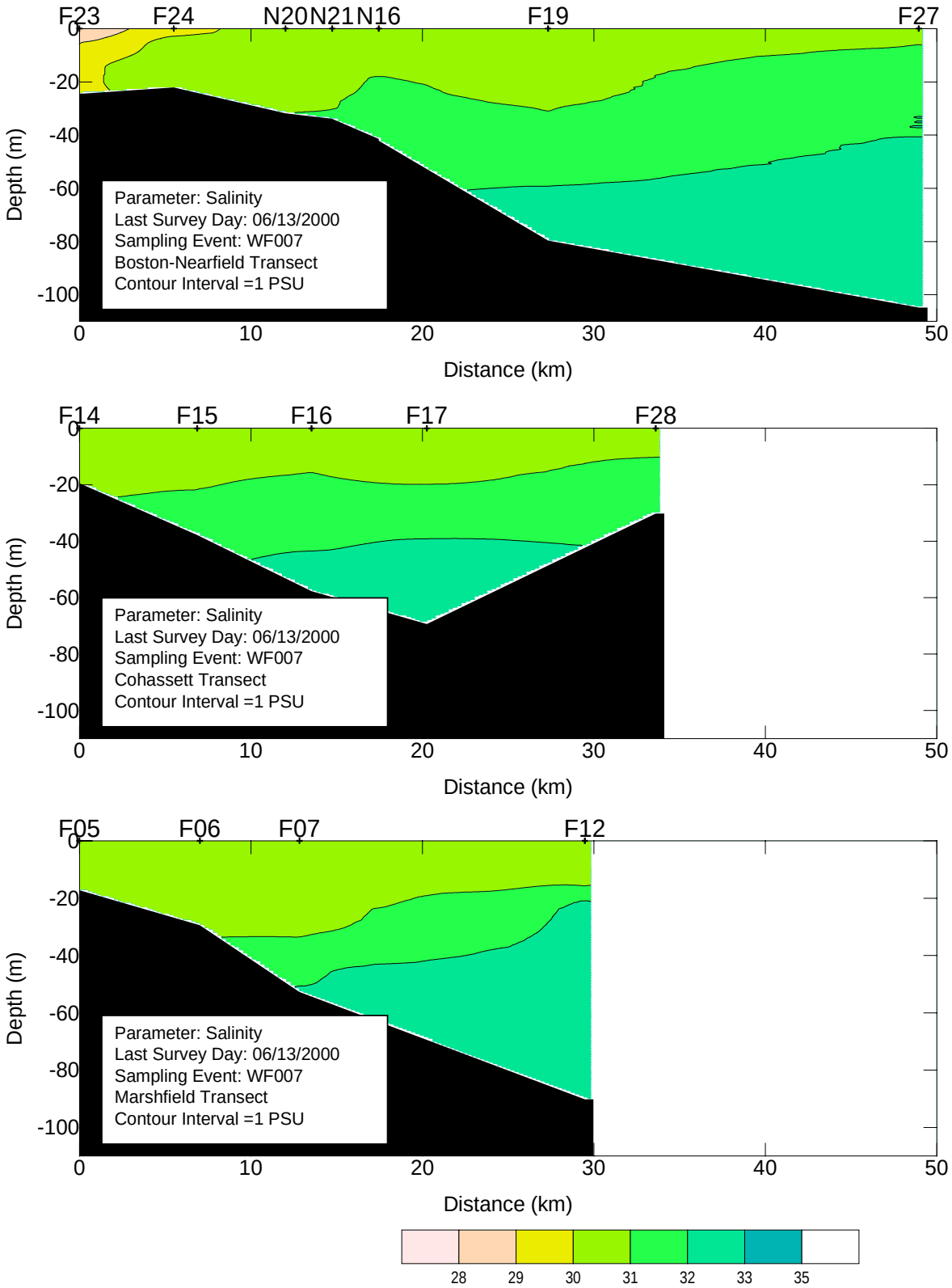


Figure 4-19. Salinity Vertical Transect for Farfield Survey WF007 (Jun 00)

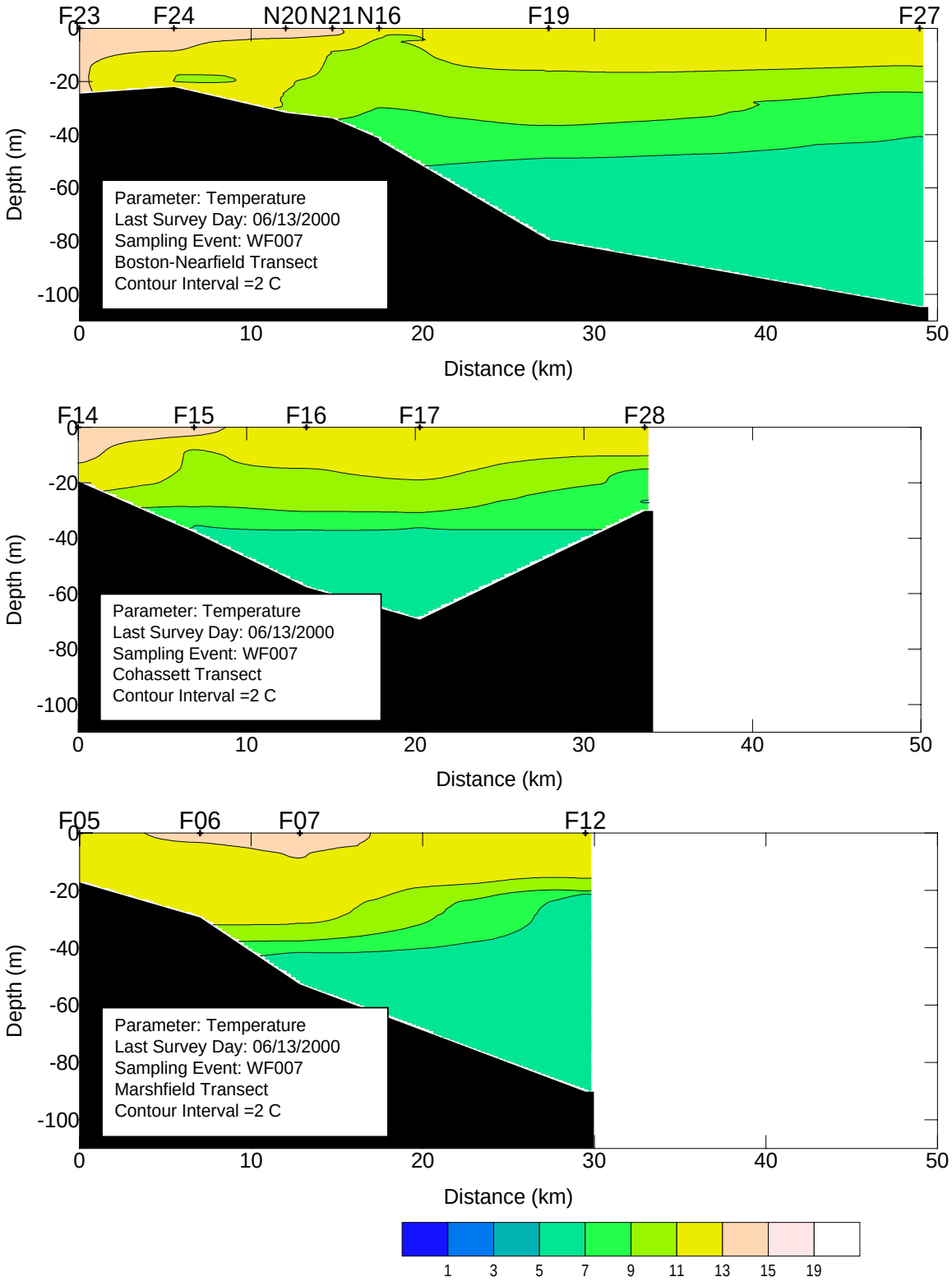


Figure 4-20. Temperature Vertical Transect for Farfield Survey WF007 (Jun 00)

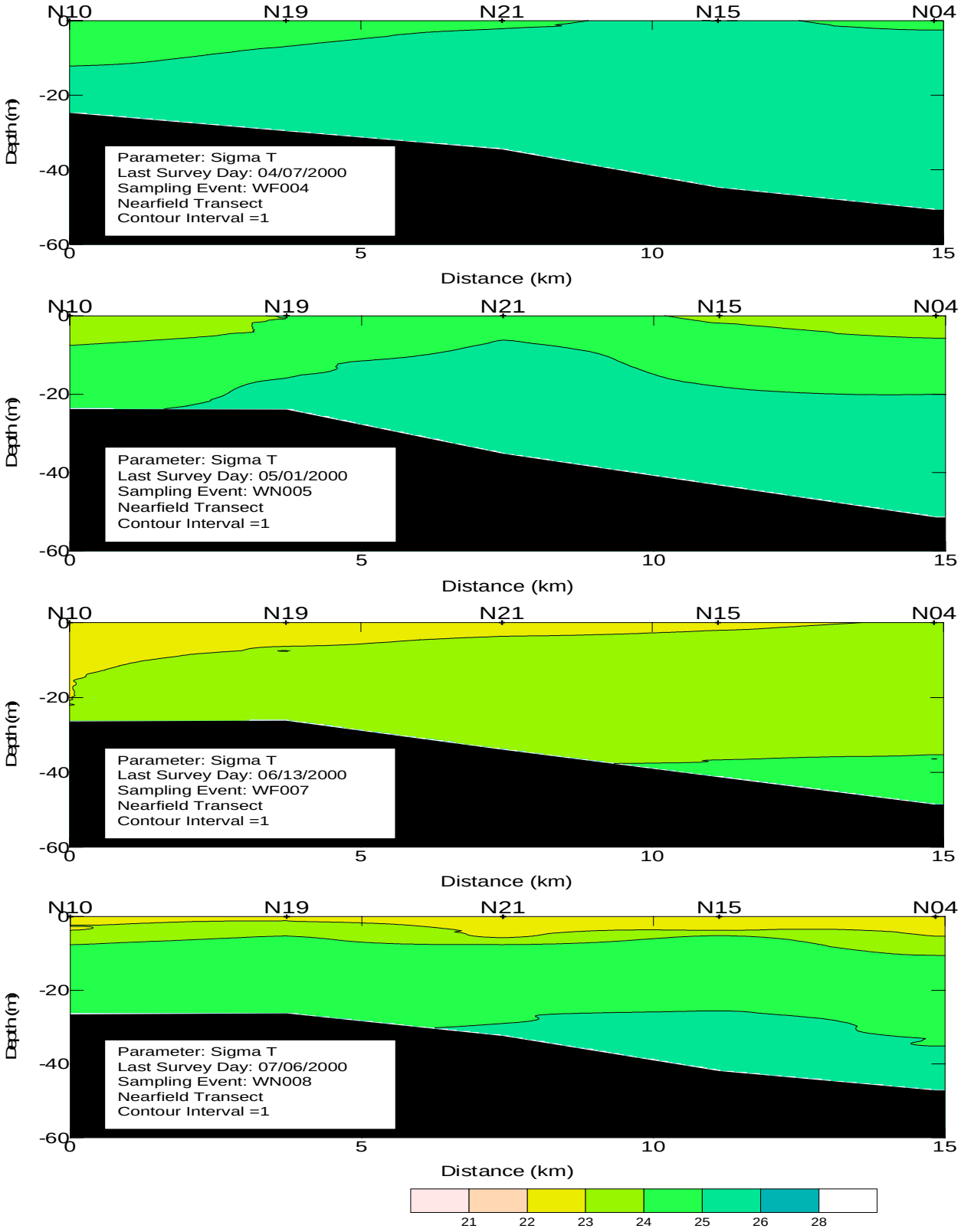
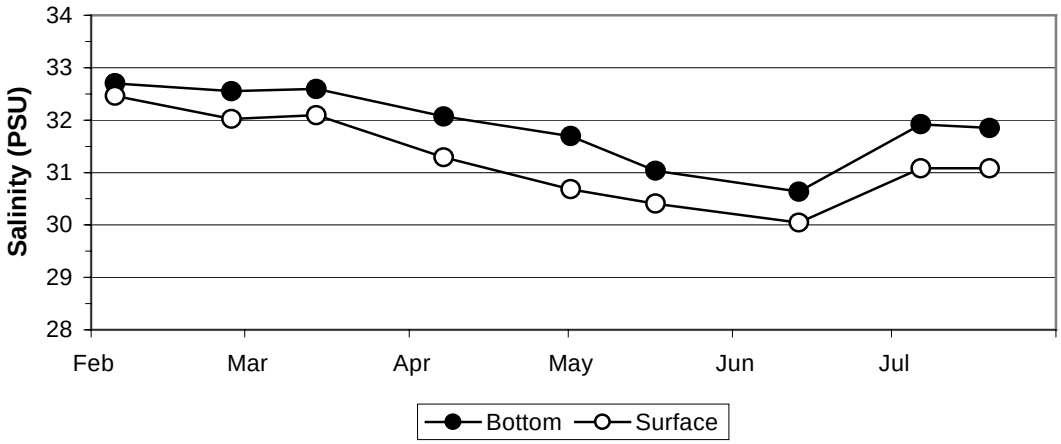
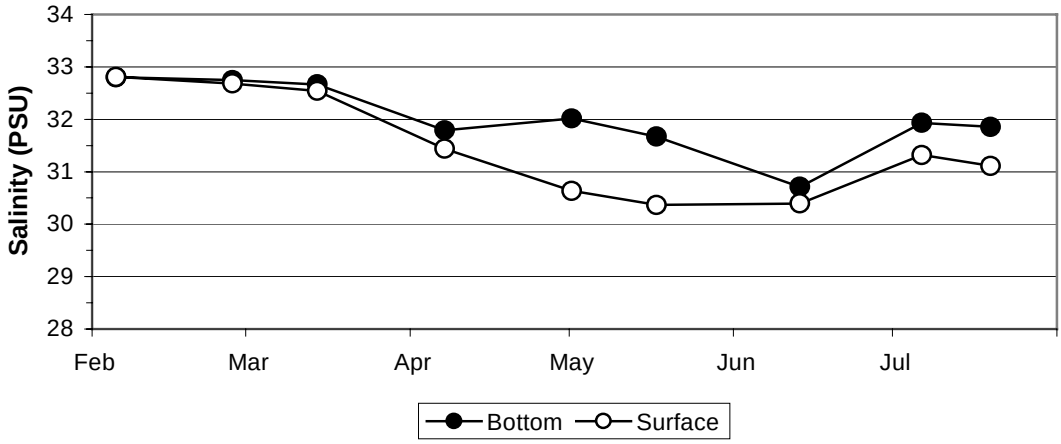


Figure 4-21. Sigma-T Vertical Nearfield Transects for Survey WF004, WN005, WF007 and WN008

(a) Inner Nearfield: N10, N11



(b) Broad Sound: N01



(c) Outer Nearfield: N04, N07, N16, N20

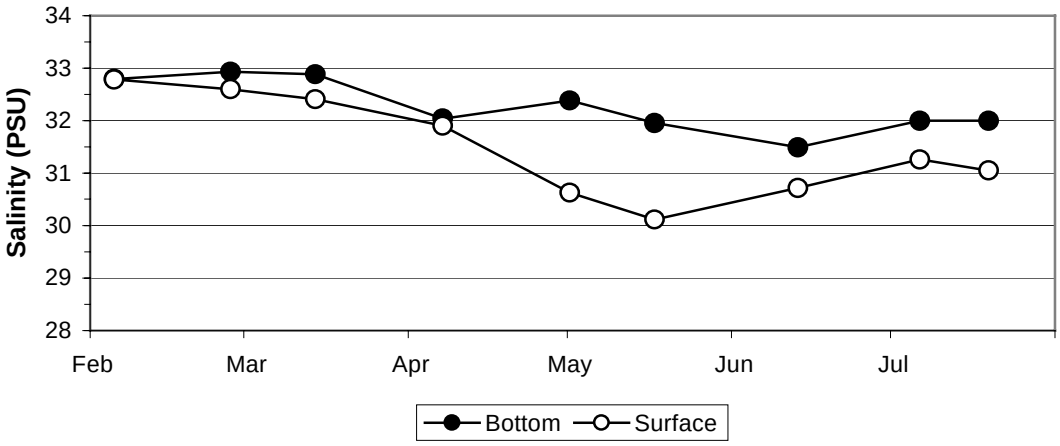
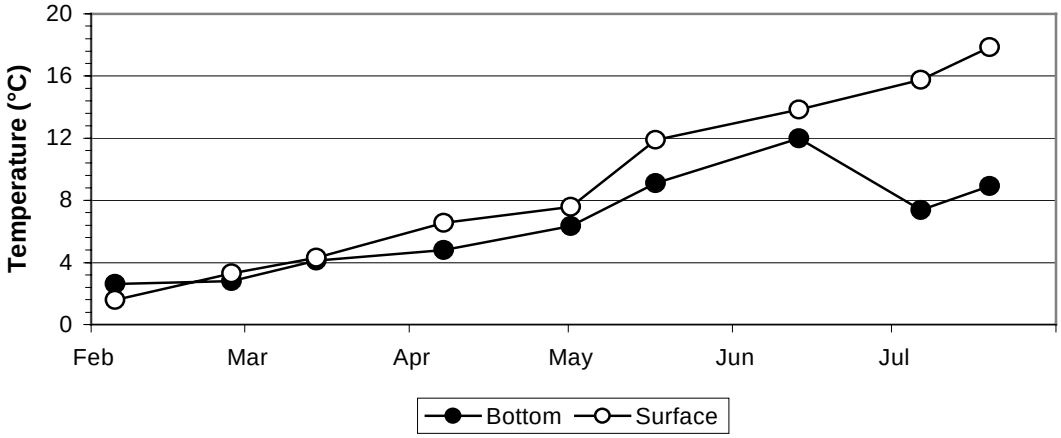
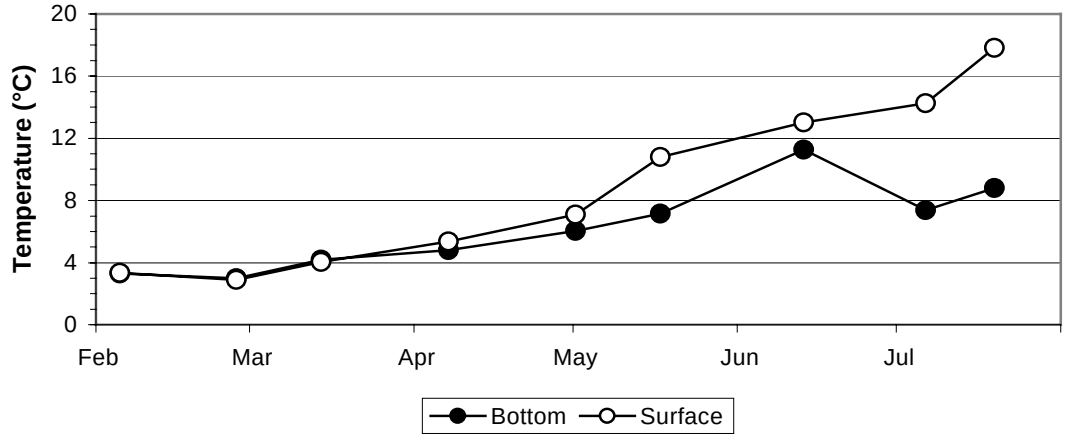


Figure 4-22. Time-Series of Average Surface and Bottom Salinity (PSU) in the Nearfield

(a) Inner Nearfield: N10, N11



(b) Broad Sound: N01



(c) Outer Nearfield: N04, N07, N16, N20

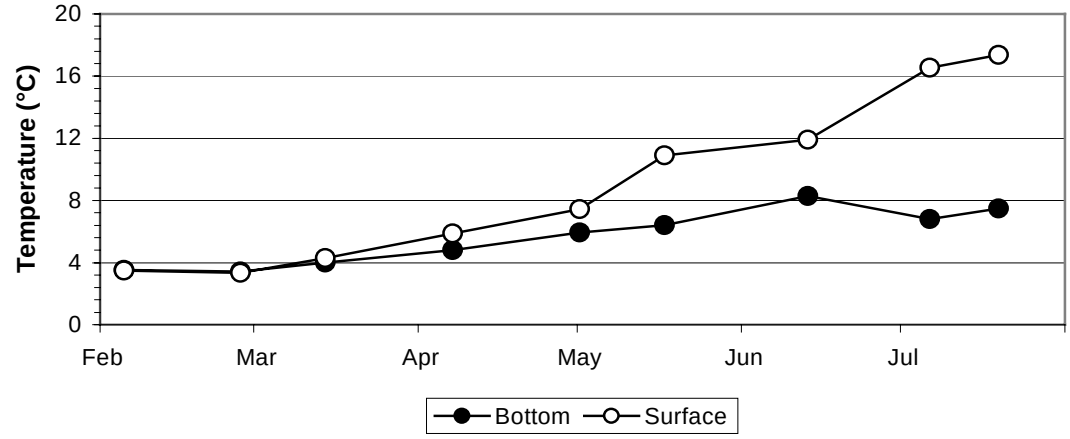


Figure 4-23. Time-Series of Average Surface and Bottom Temperature (°C) in the Nearfield

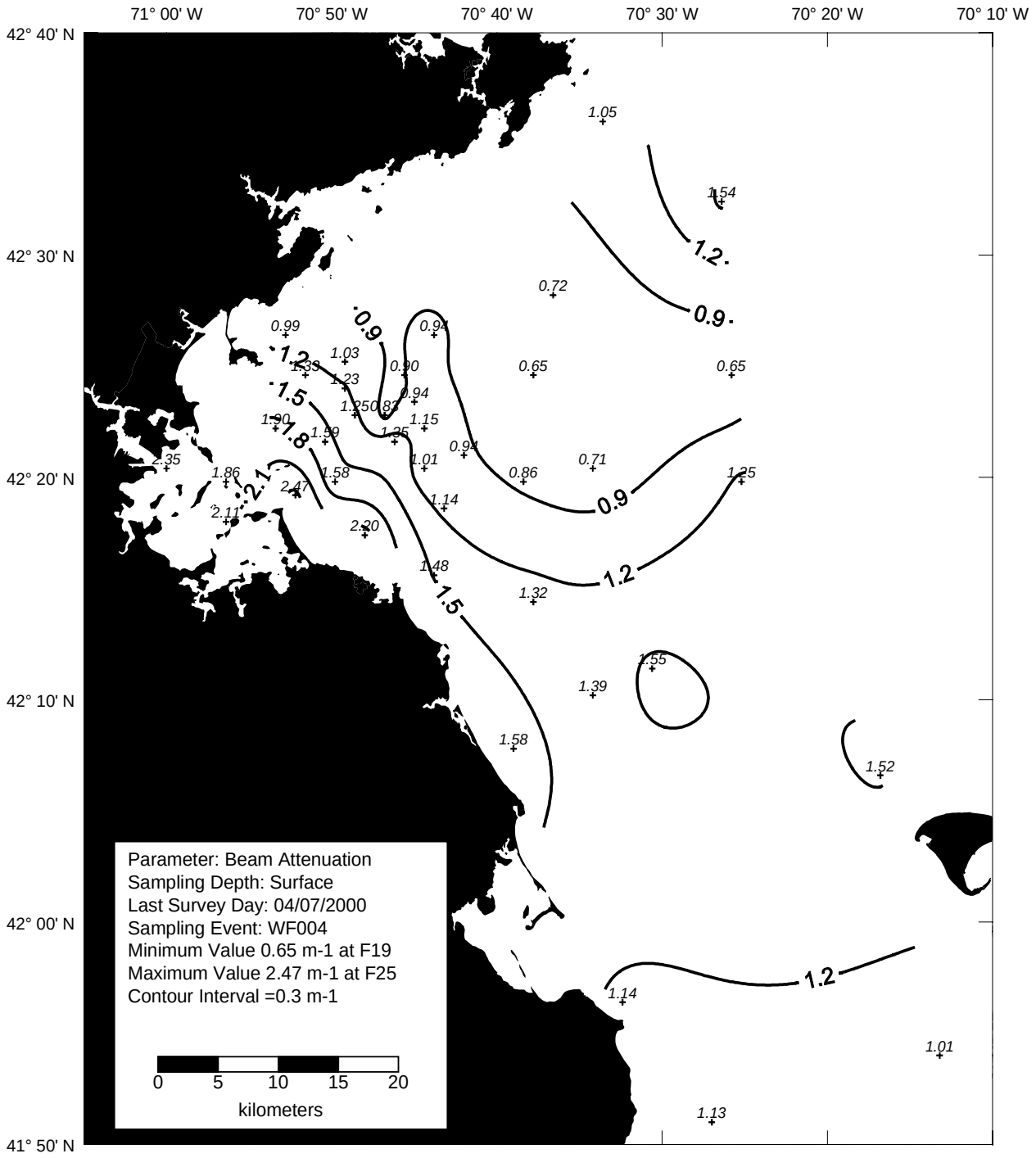


Figure 4-24. Beam Attenuation Surface Contour Plot for Farfield Survey WF004 (Apr 00)

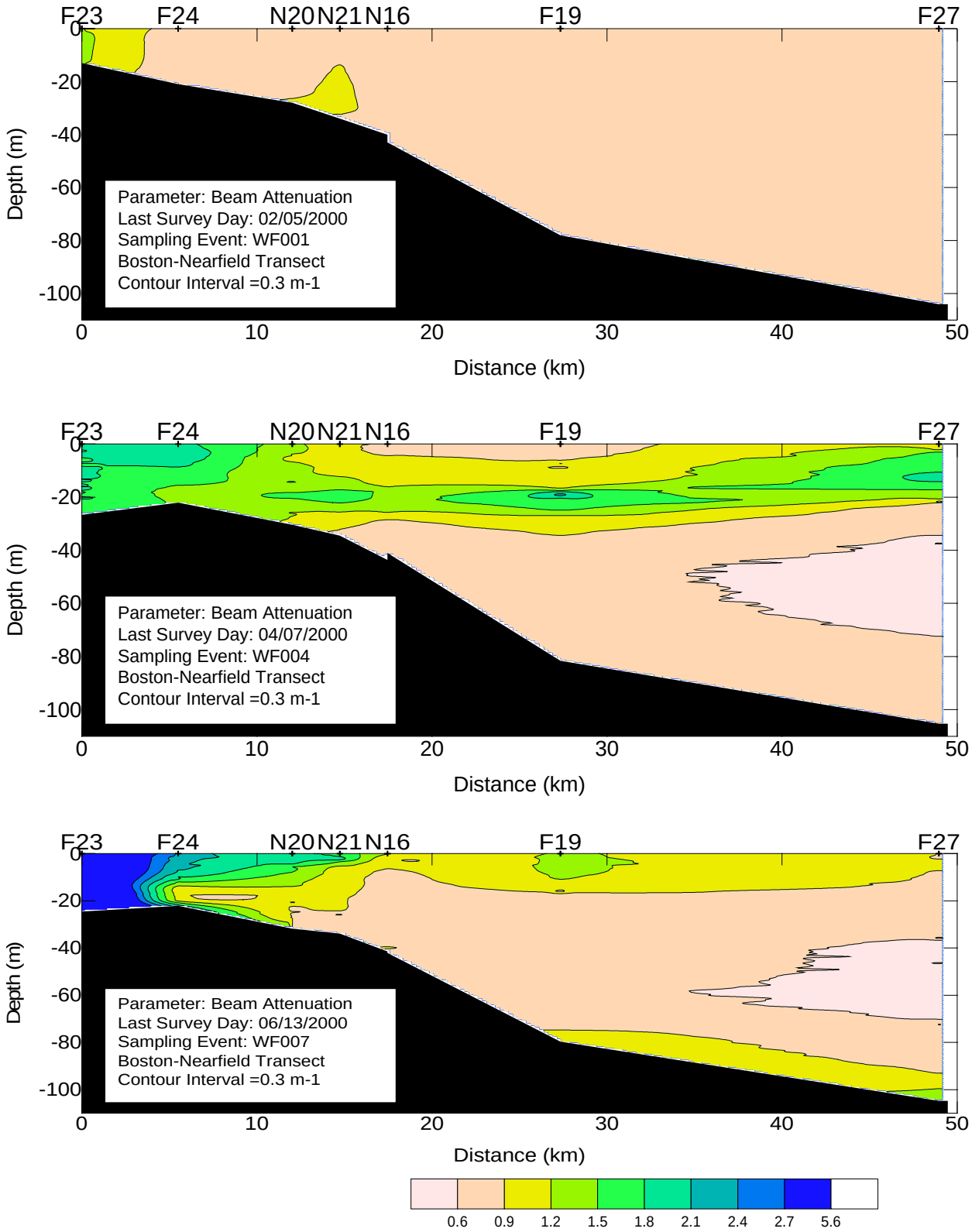


Figure 4-25. Beam Attenuation Vertical Contour Plots along the Boston-Nearfield Transect for Surveys WF001, WF004, and WF007

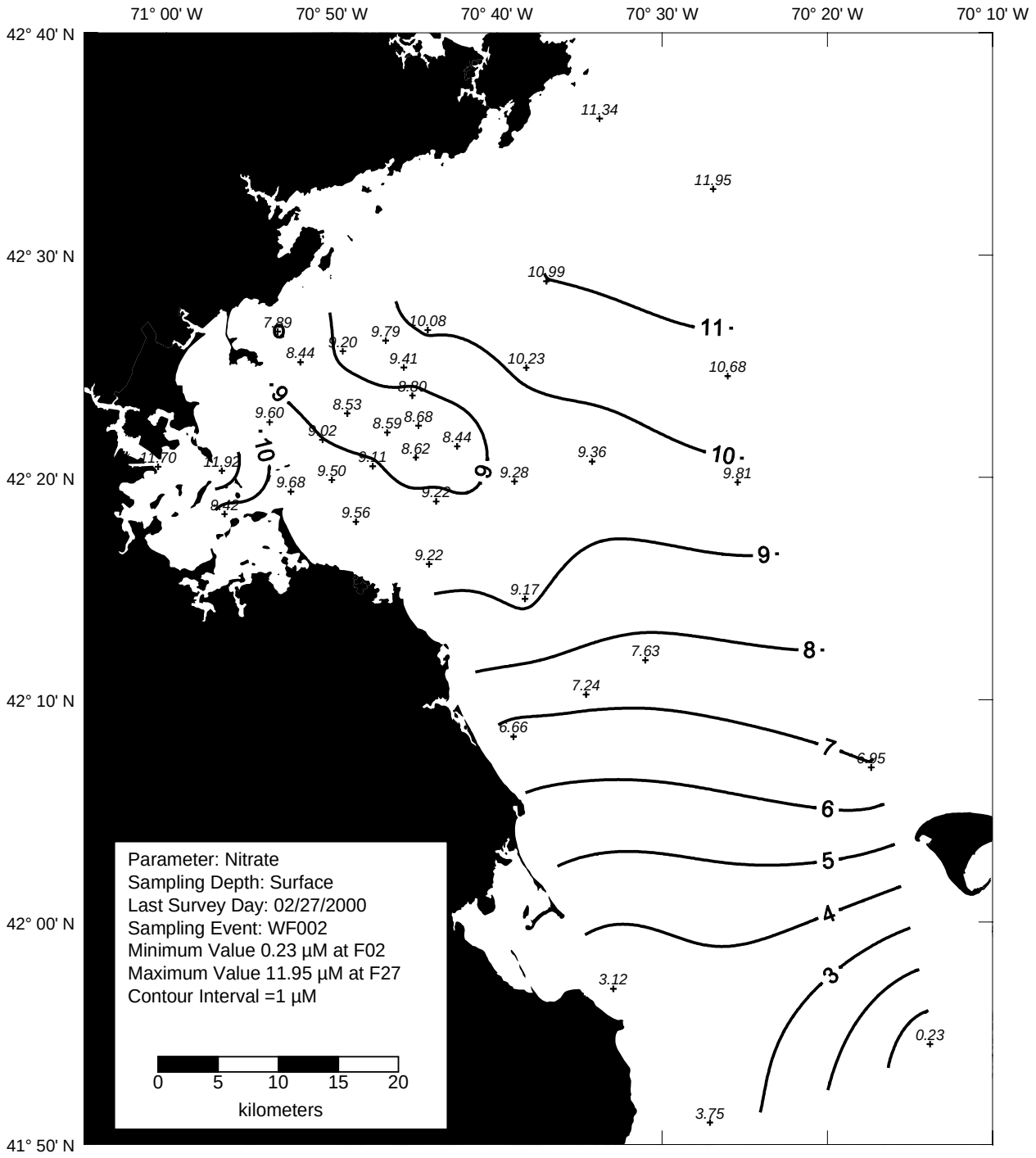


Figure 4-26. Nitrate Surface Contour Plot for Farfield Survey WF002 (Feb 00)

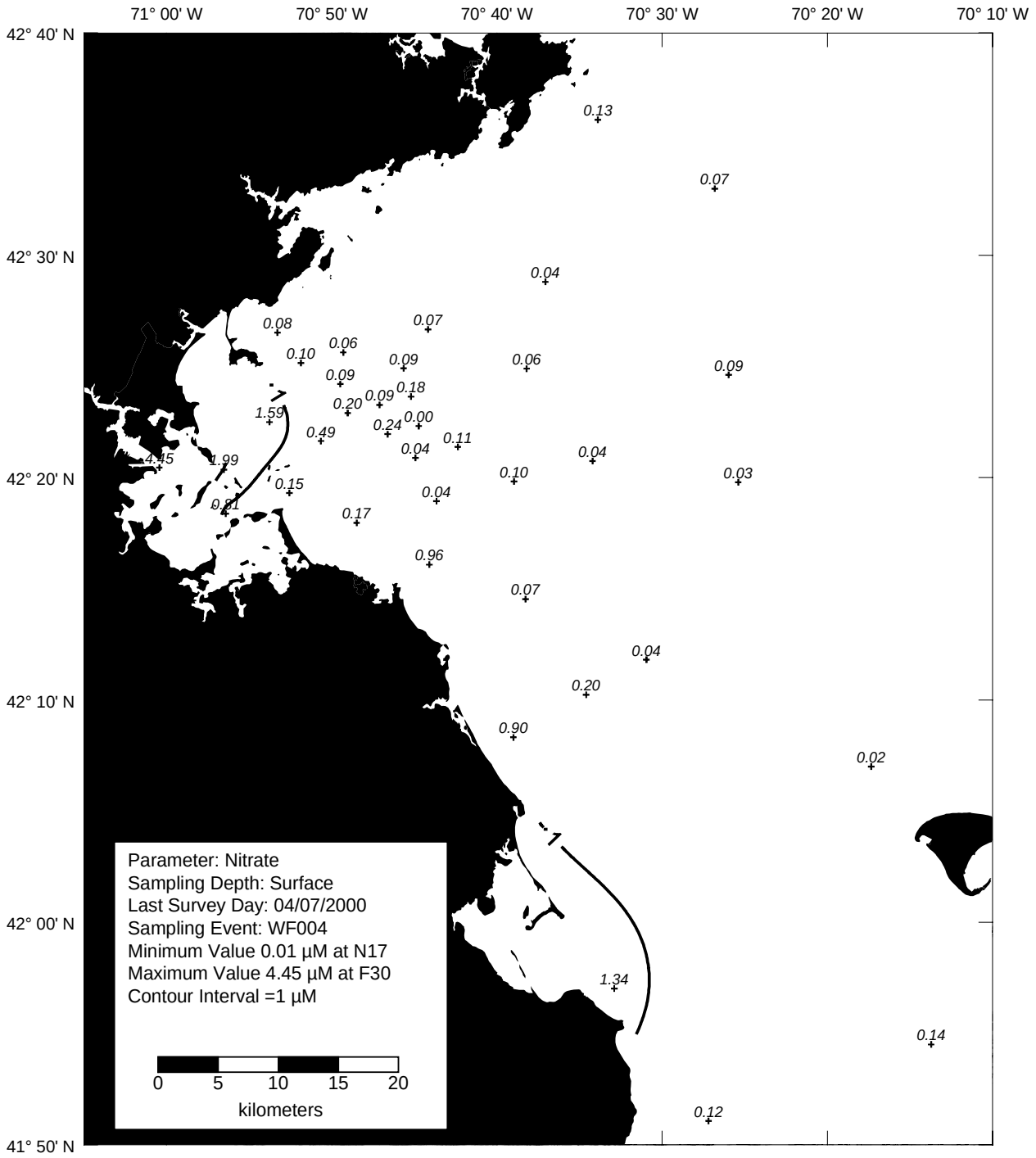


Figure 4-27. Nitrate Surface Contour Plot for Farfield Survey WF004 (Apr 00)

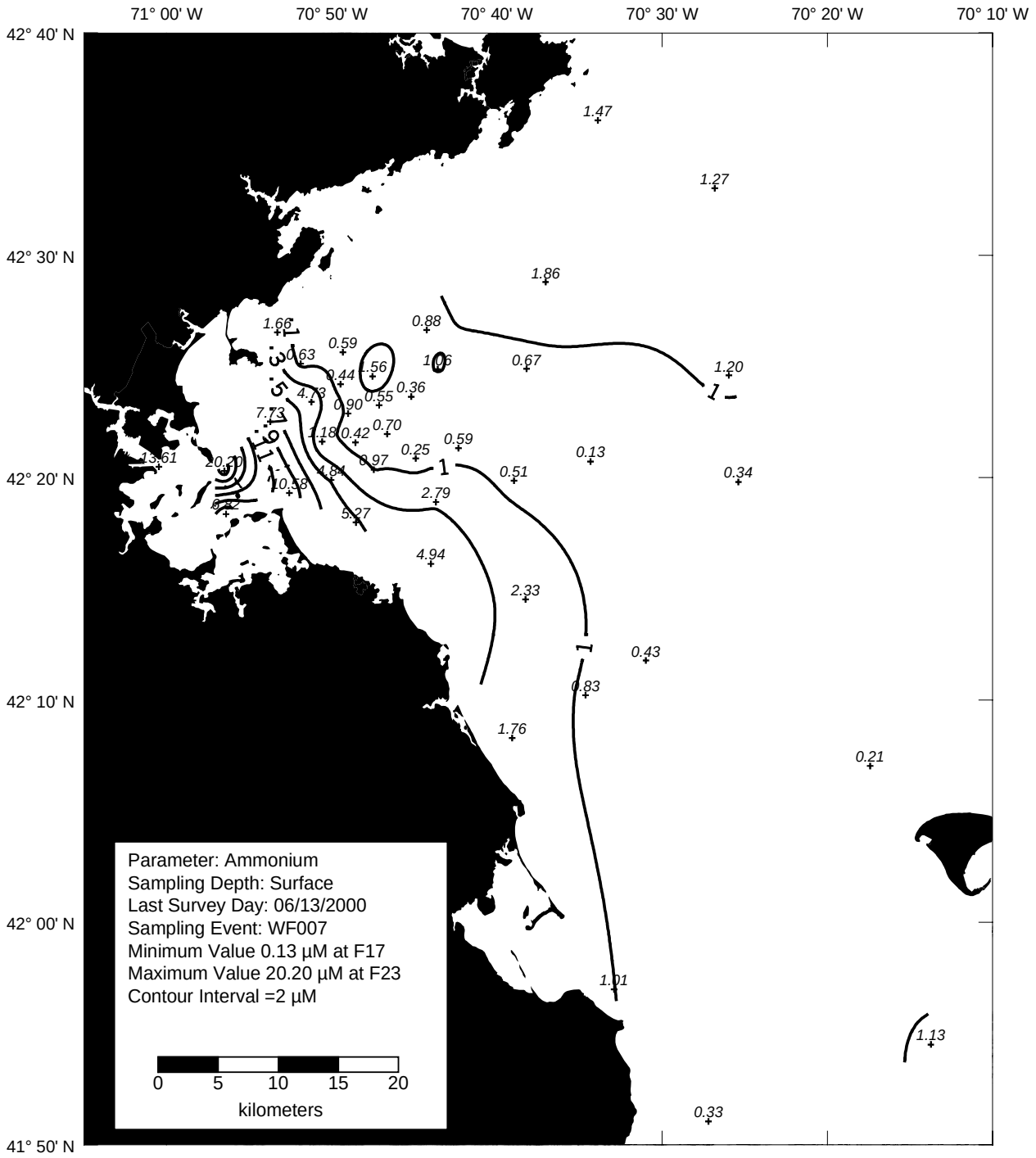


Figure 4-28. Ammonium Surface Contour Plot for Farfield Survey WF007 (Jun 00)

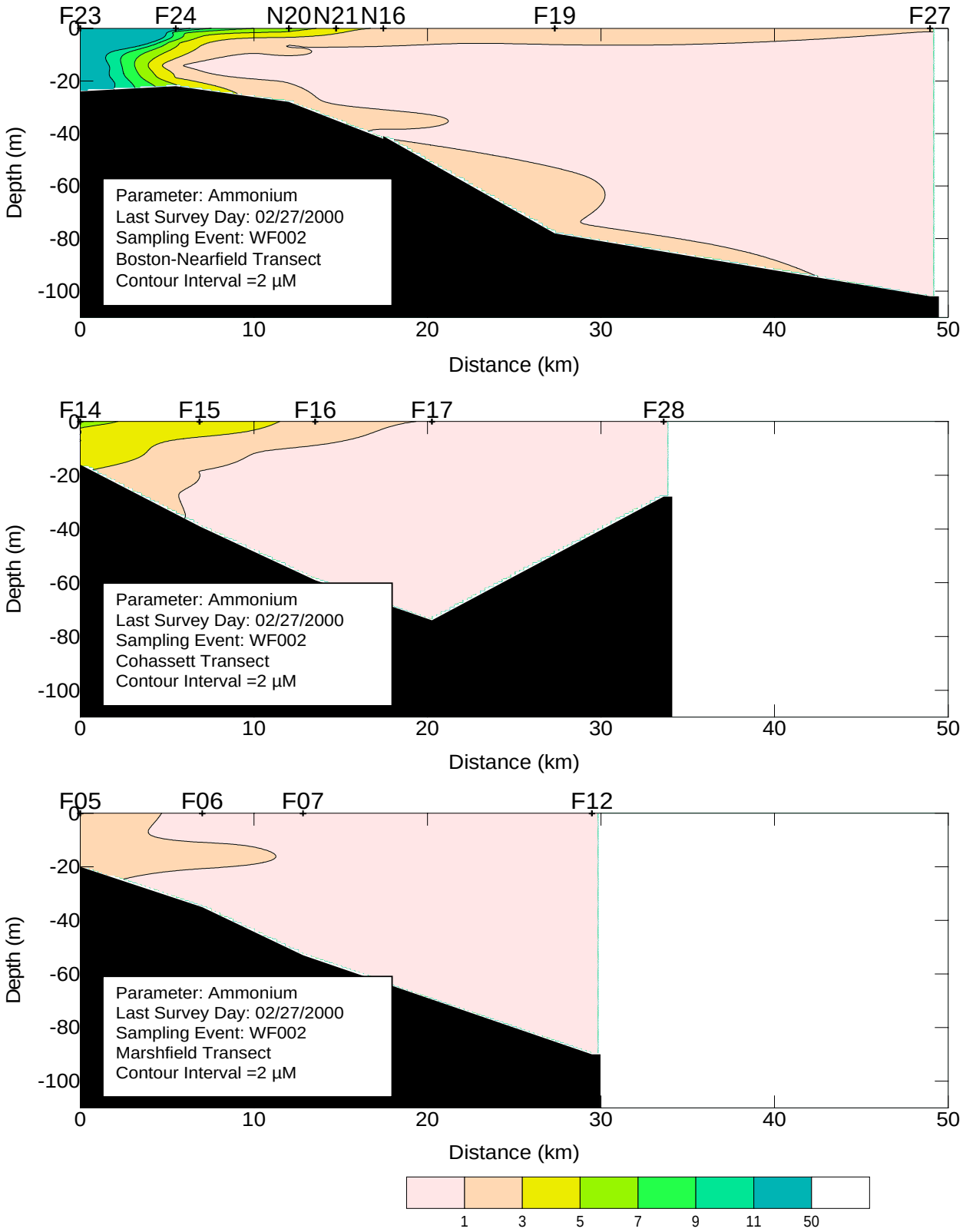


Figure 4-29. Ammonium Vertical Transect for Farfield Survey WF002 (Feb 00)

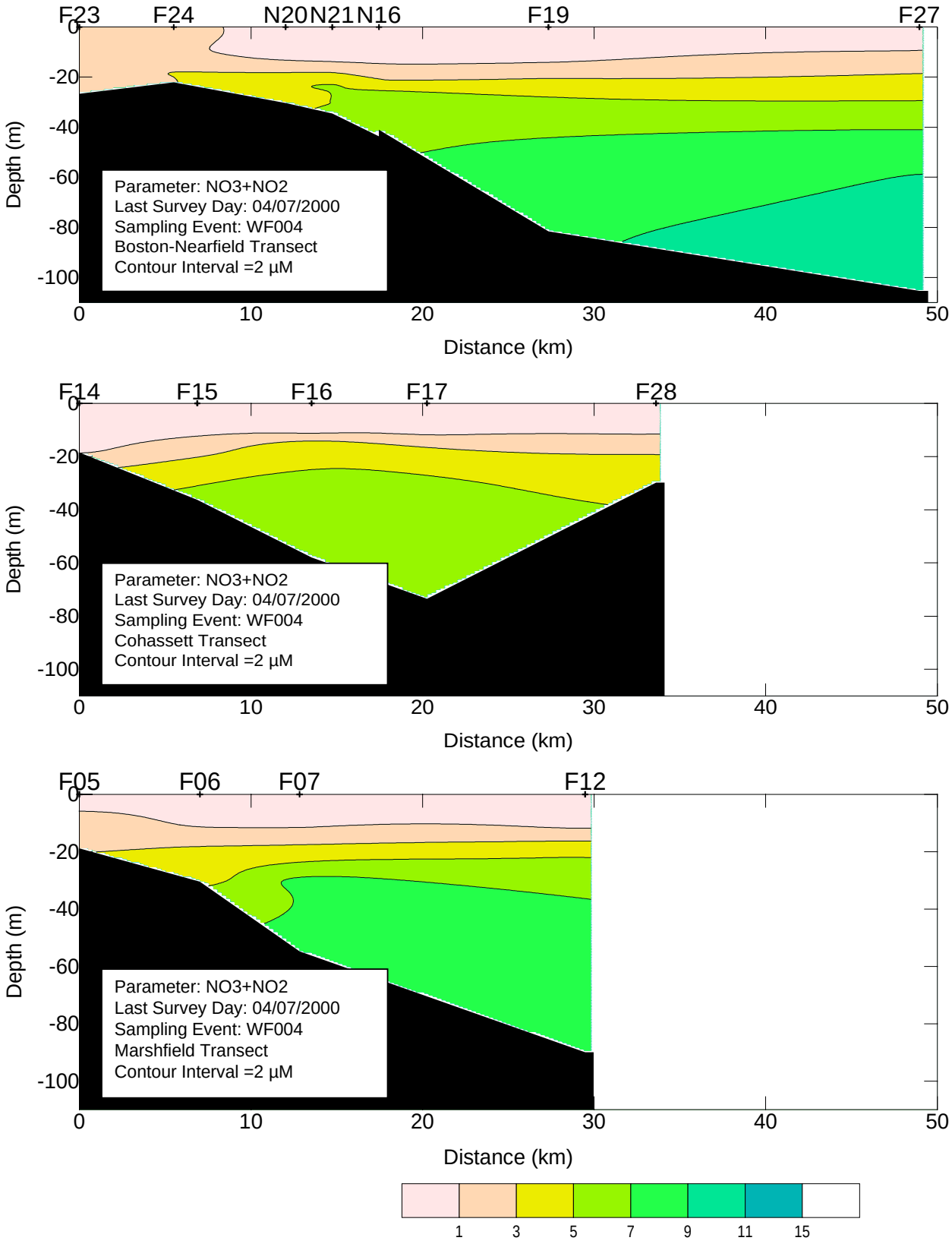


Figure 4-30. Nitrate Plus Nitrite Vertical Transect Plots for Farfield Survey WF004 (Apr 00)

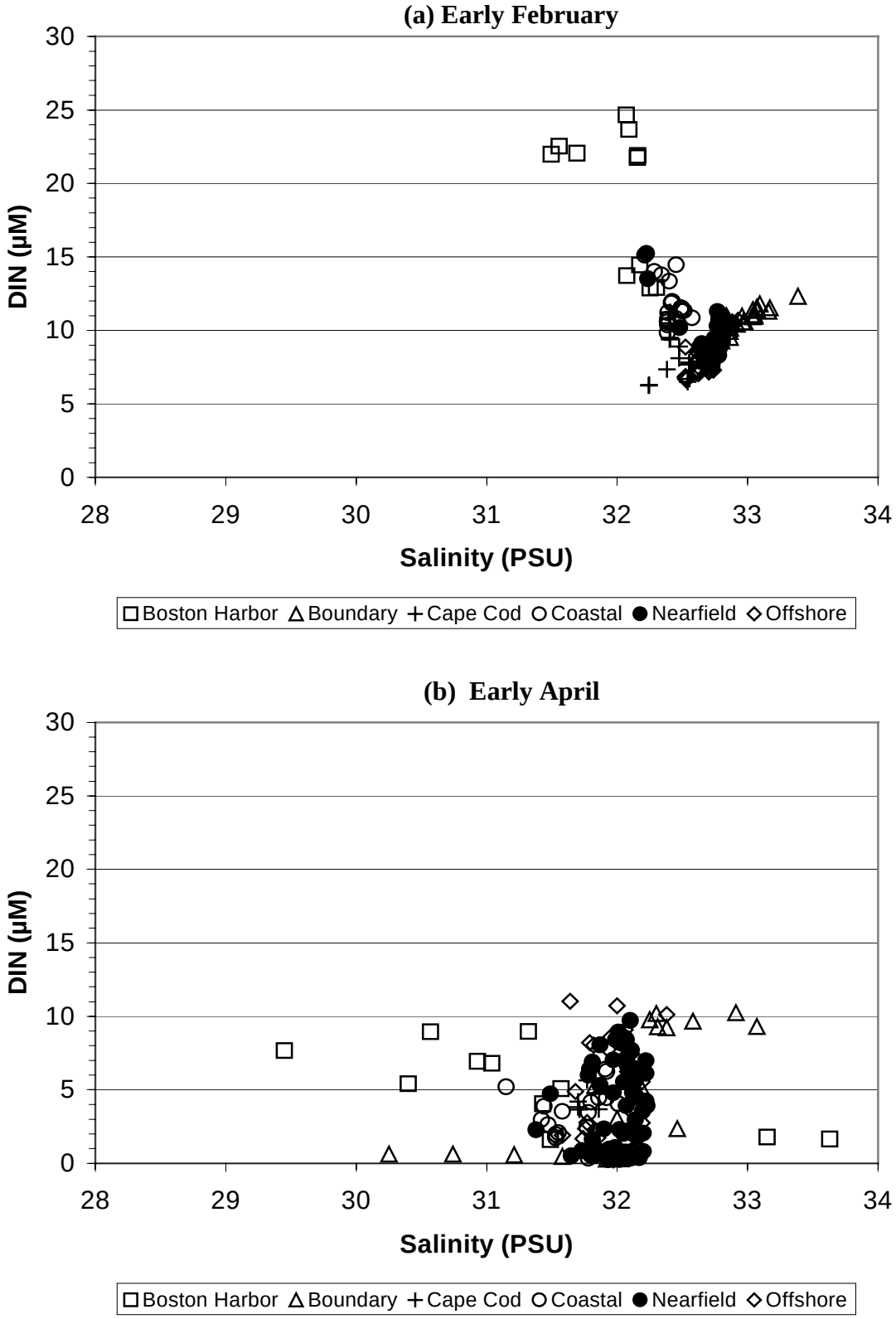


Figure 4-31. DIN vs. Salinity for All Depths during Farfield Surveys WF001 (Feb 00) and WF004 (Apr 00)

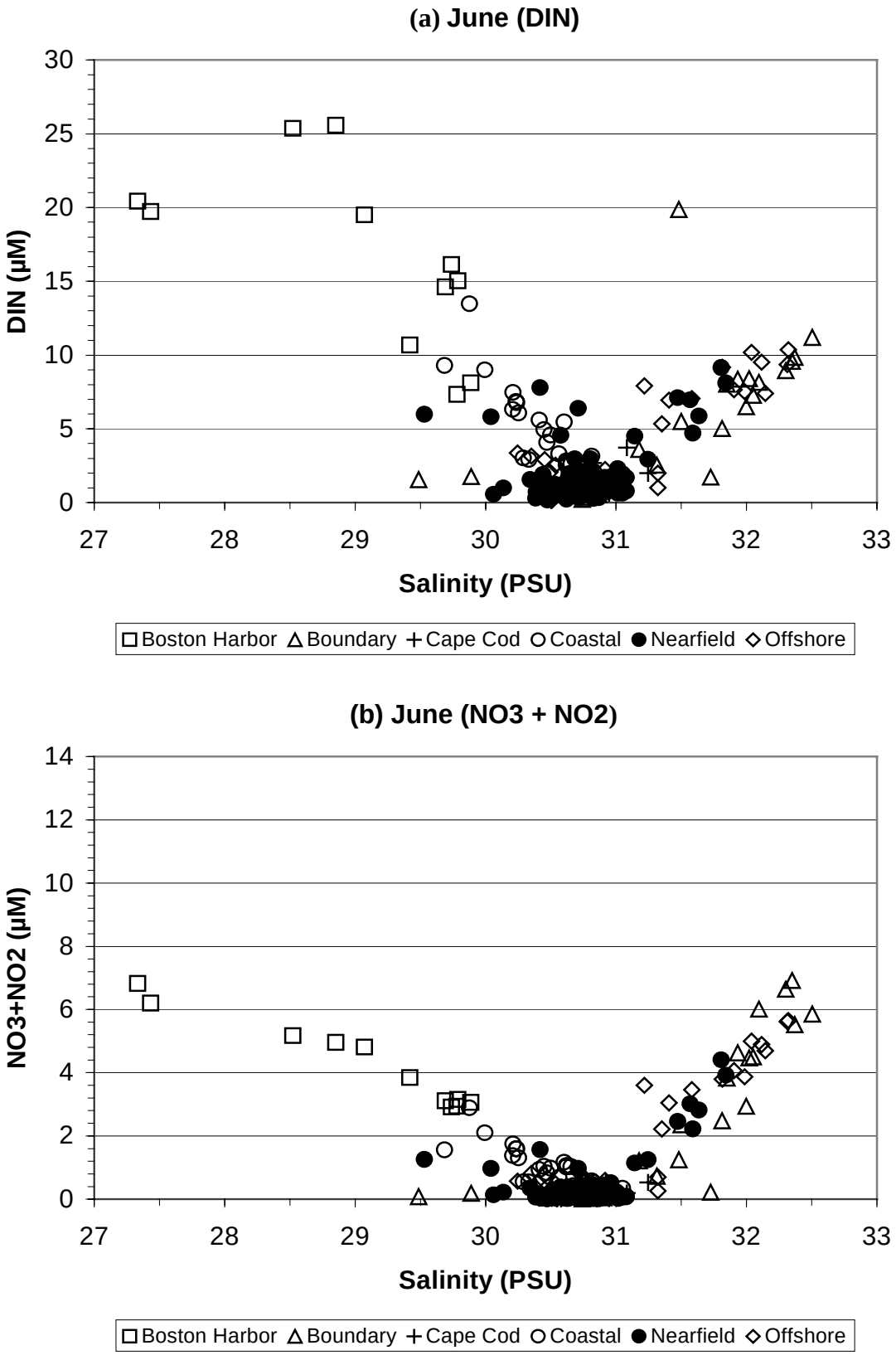


Figure 4-32. DIN vs. Salinity and Nitrate plus Nitrite vs. Salinity for All Depths during Farfield Survey WF007 (Jun 00)

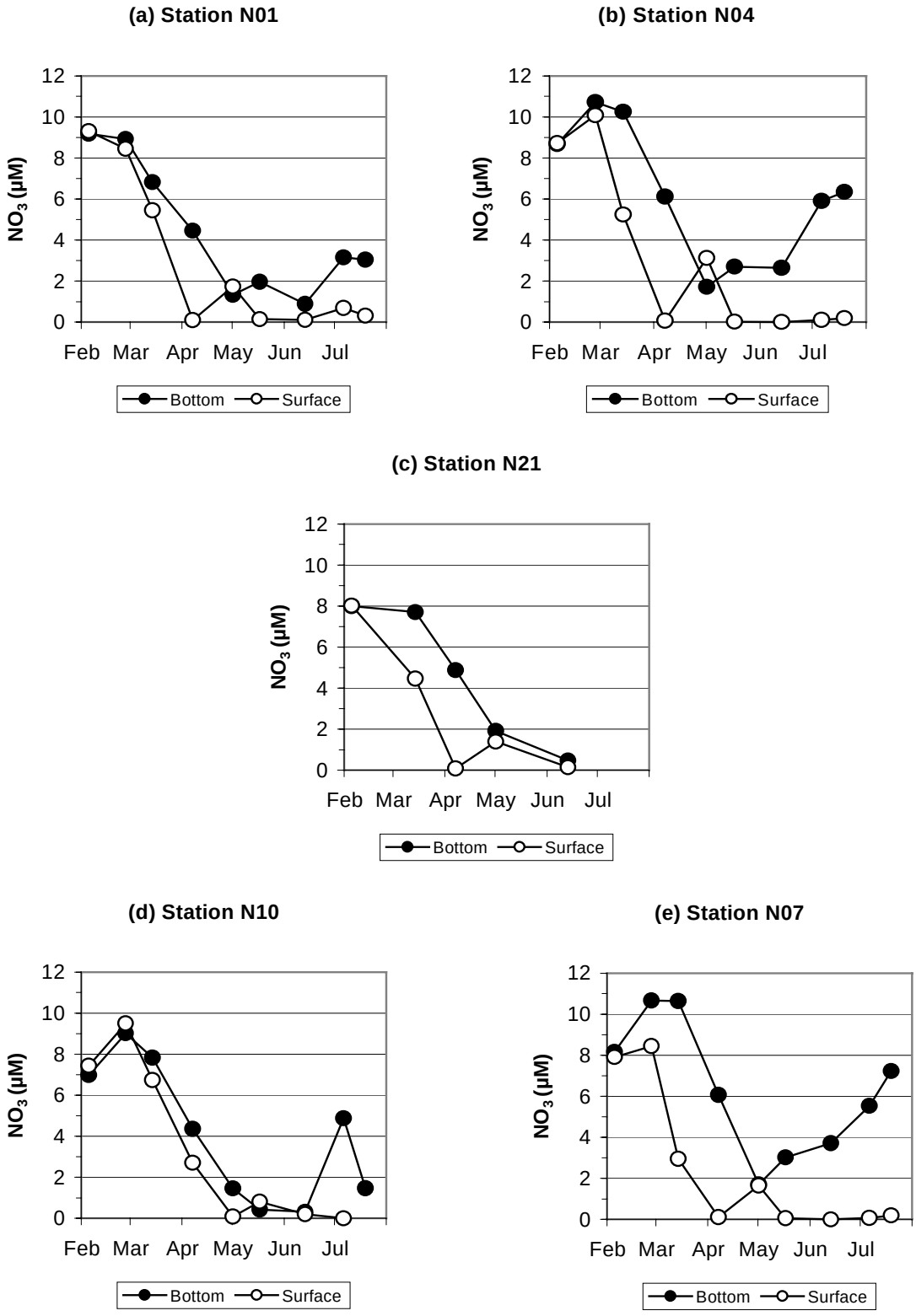


Figure 4-33. Time-Series of Surface and Bottom Water Nitrate Concentration at Five Nearfield Stations

Note: The arrangement of the figures on this page mimic the relative positions of the stations.

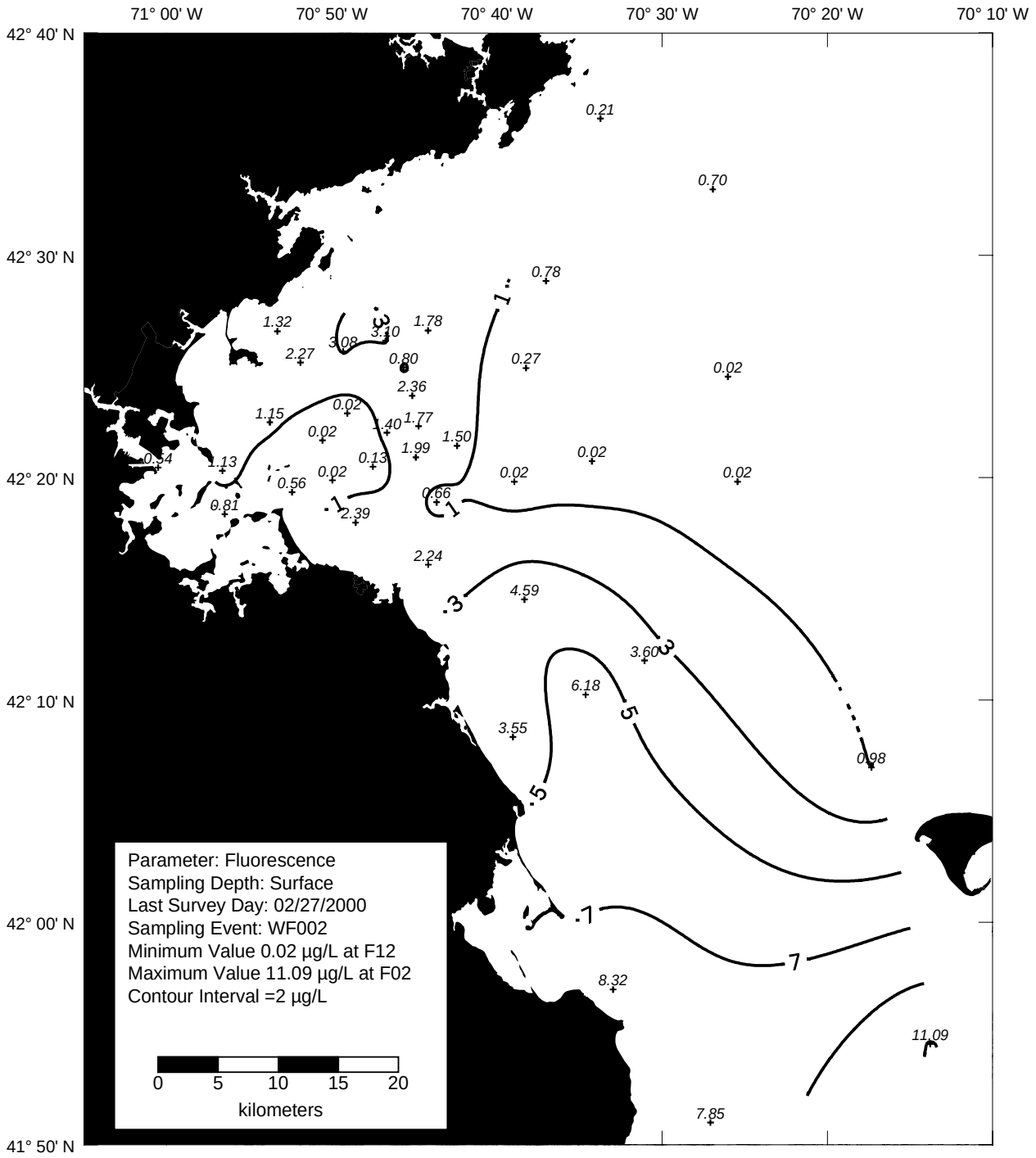


Figure 4-34. Fluorescence Surface Contour Plot for Farfield Survey WF002 (Feb 00)

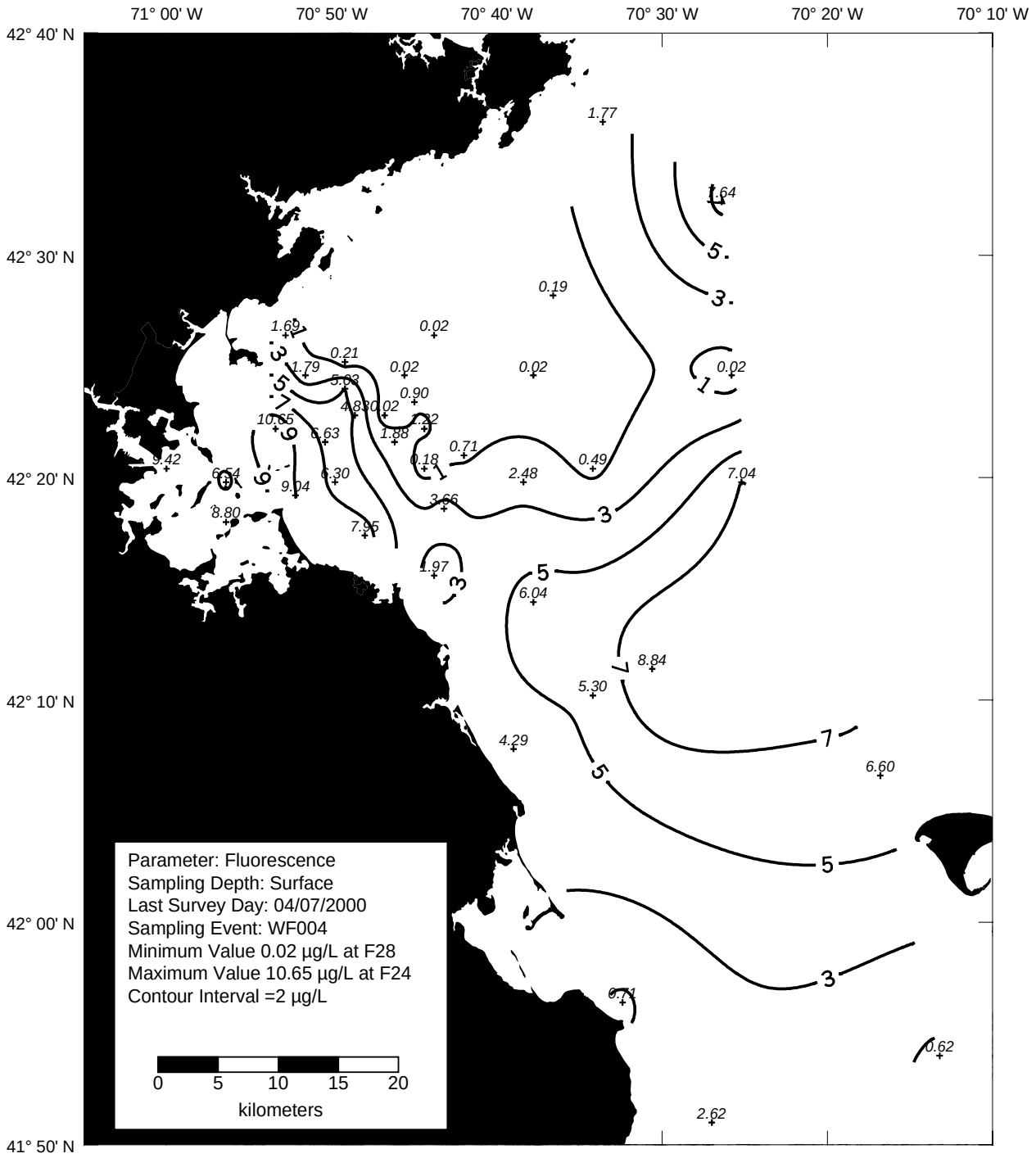


Figure 4-35. Fluorescence Surface Contour Plot for Farfield Survey WF004 (Apr 00)

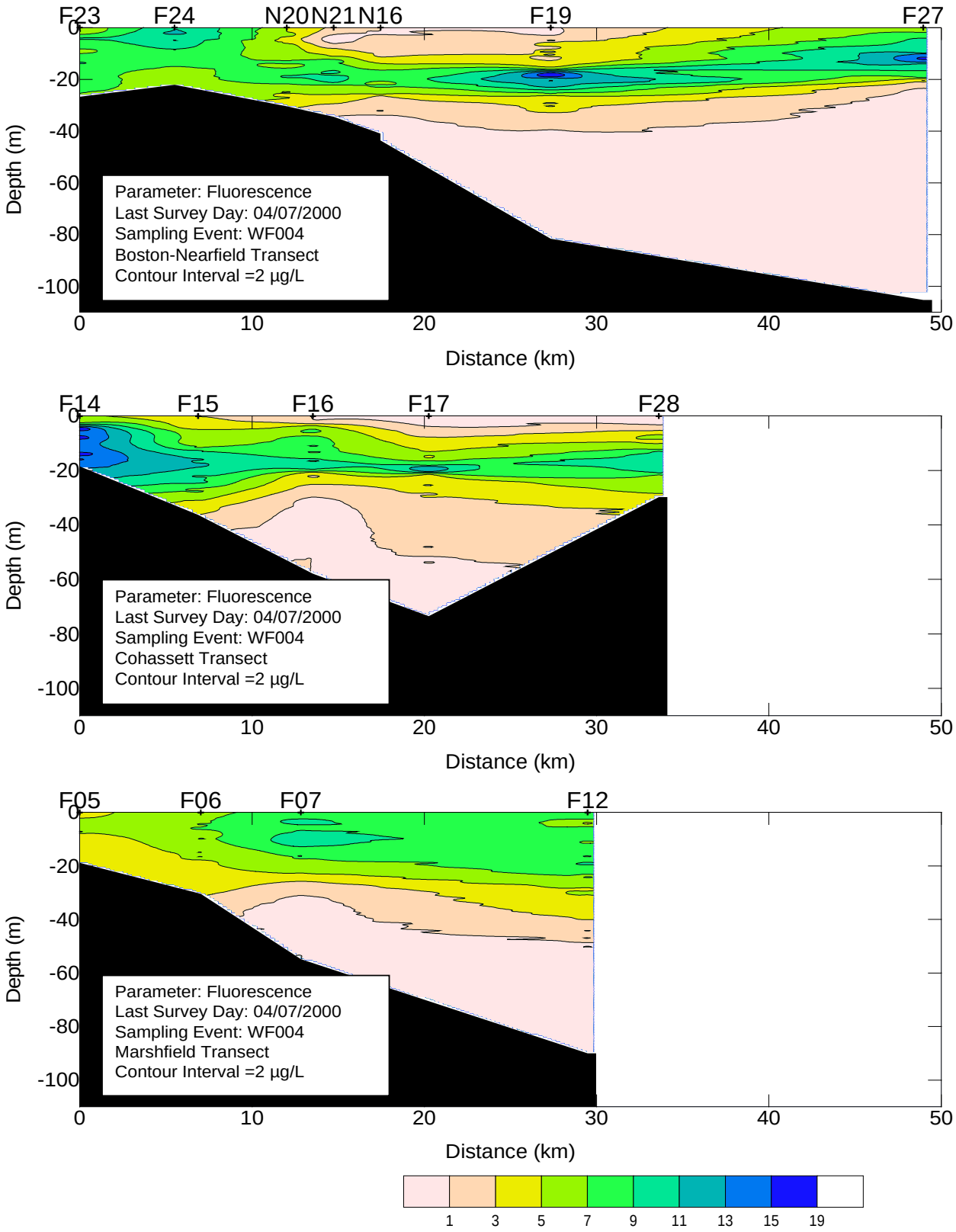


Figure 4-36. Fluorescence Vertical Transect Plots for Farfield Survey WF004 (Apr 00)

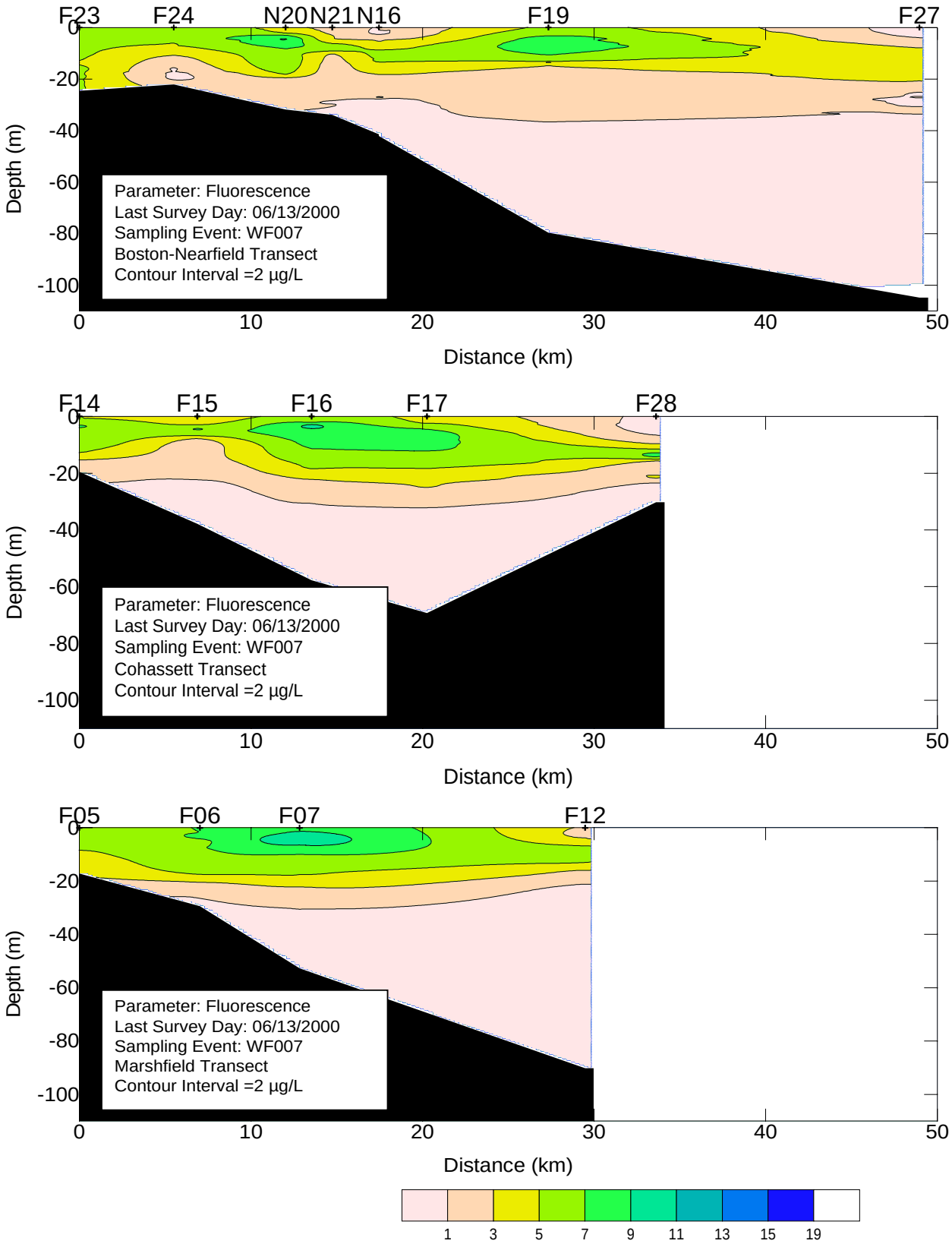


Figure 4-37. Fluorescence Vertical Transect Plots for Farfield Survey WF007 (Jun 00)

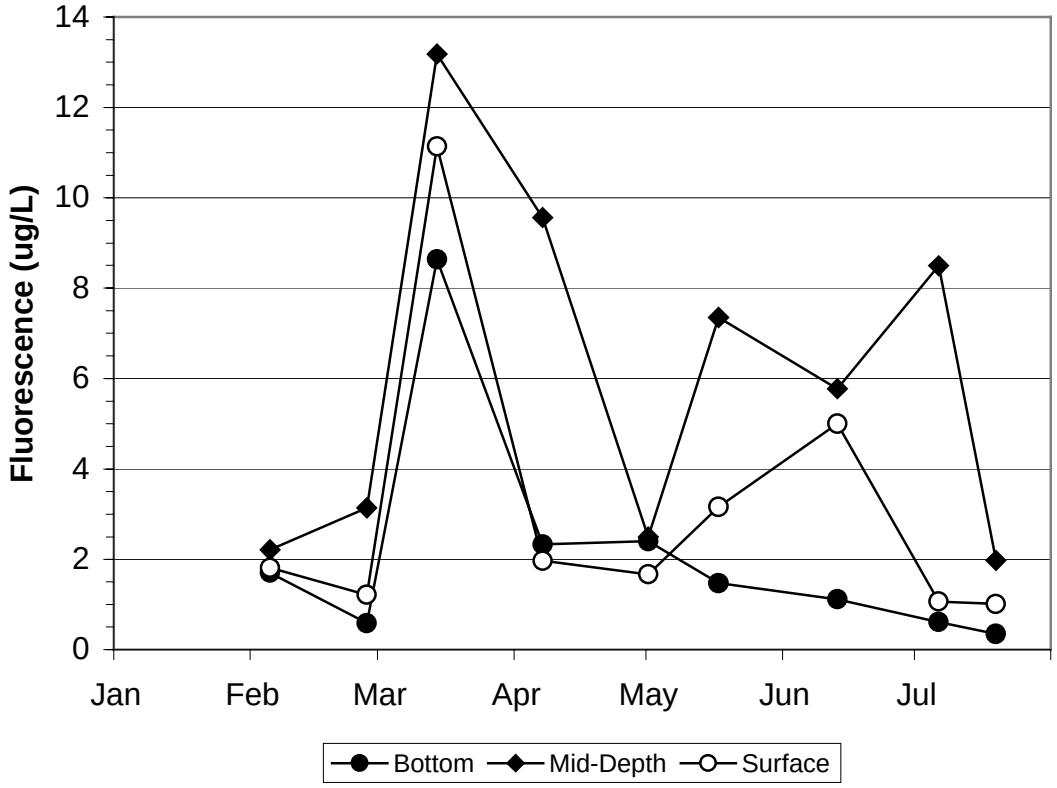


Figure 4-38. Time-Series of Bottom, Mid-Depth, and Surface Survey Mean Chlorophyll Concentration in the Nearfield

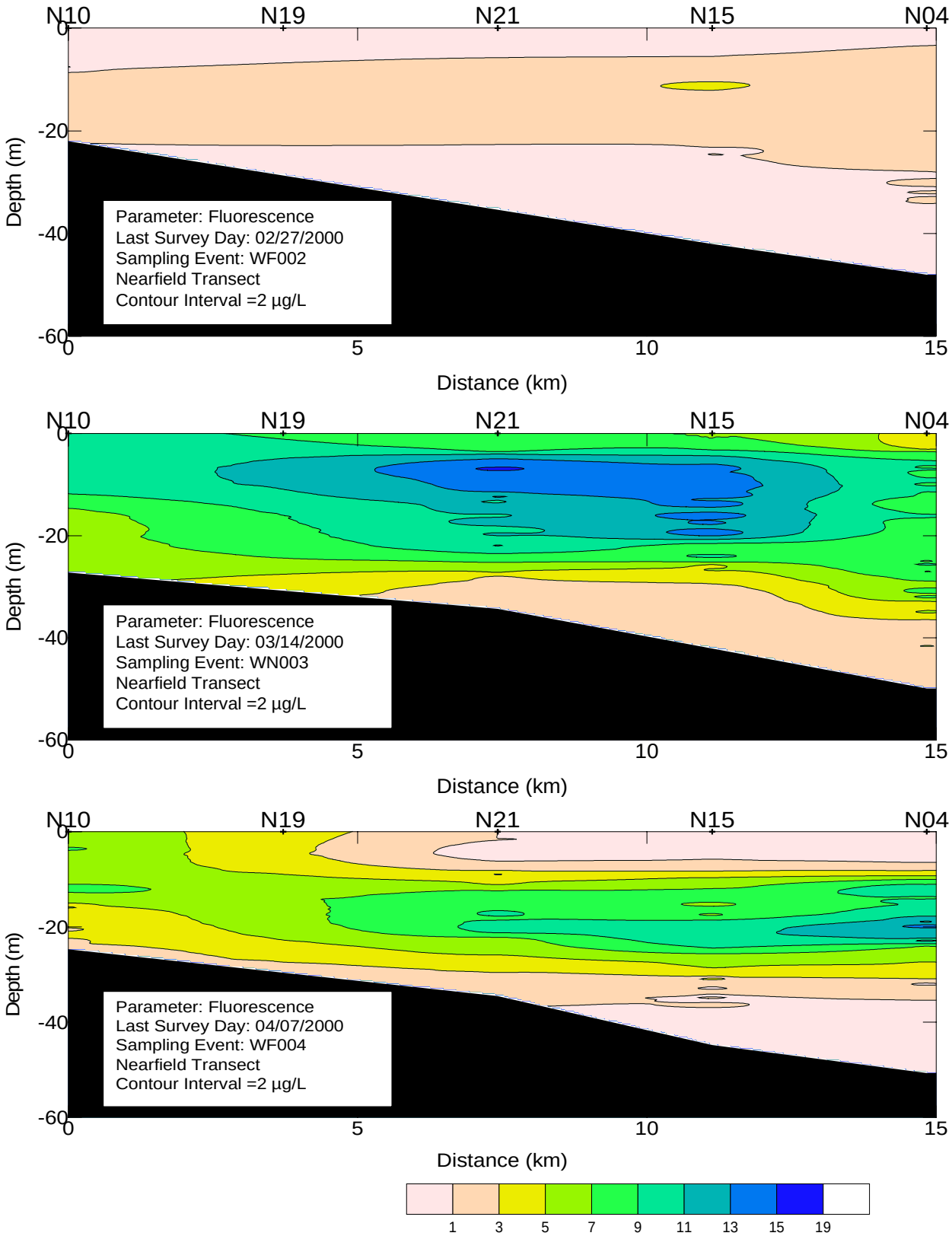


Figure 4-39. Fluorescence Vertical Nearfield Transect Plots for Surveys WF002, WN003, and WF004

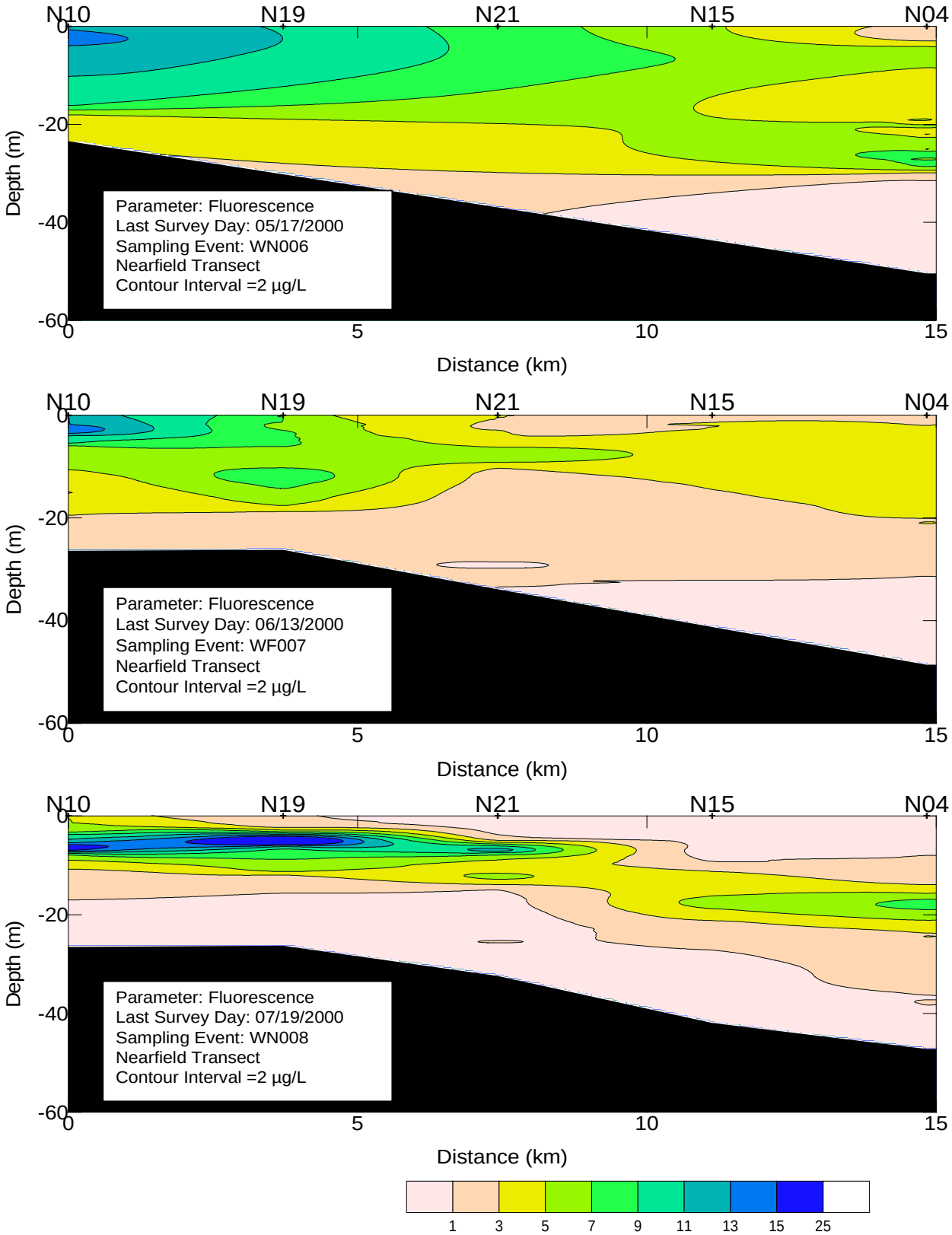
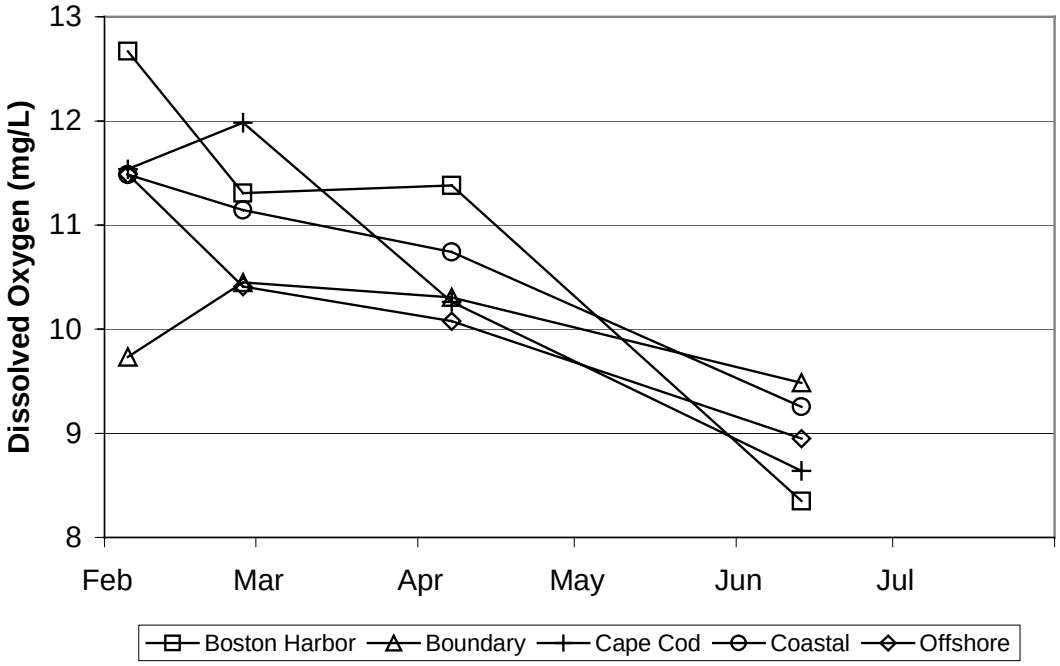


Figure 4-40. Fluorescence Vertical Nearfield Transect Plots for Surveys WN006, WF007, and WN008

(a) Dissolved Oxygen Concentration



(b) Dissolved Oxygen Percent Saturation

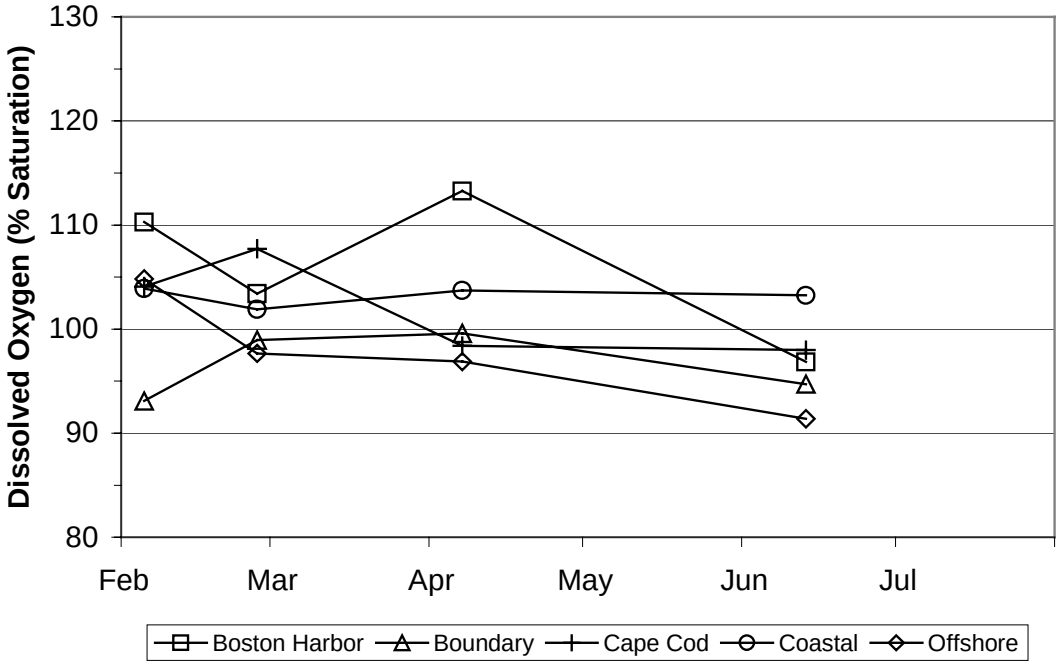


Figure 4-41. Time-Series of Bottom Water Average DO Concentration and Percentage Saturation in the Farfield

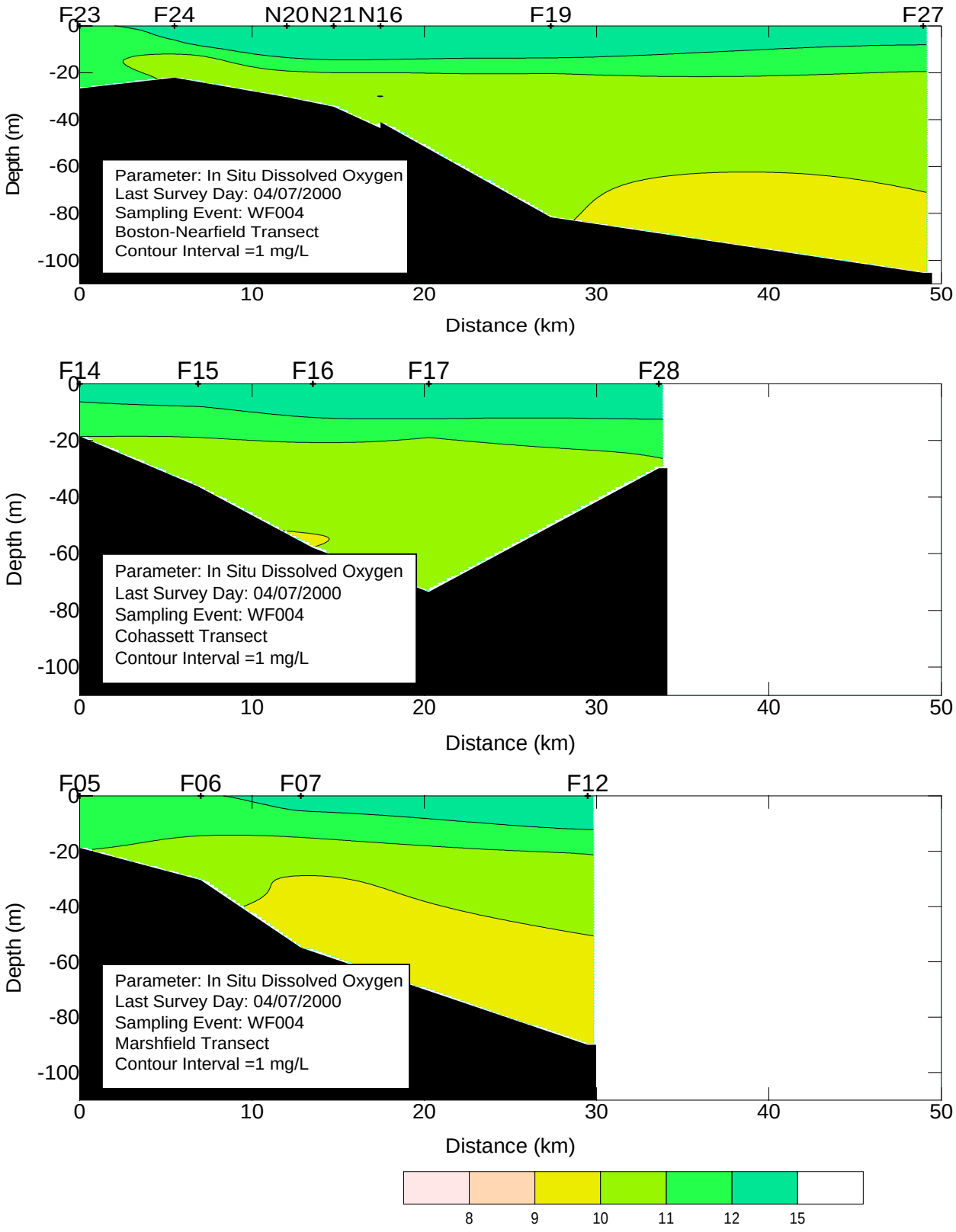


Figure 4-42. Dissolved Oxygen Vertical Transects for Survey WF004 (Apr 00)

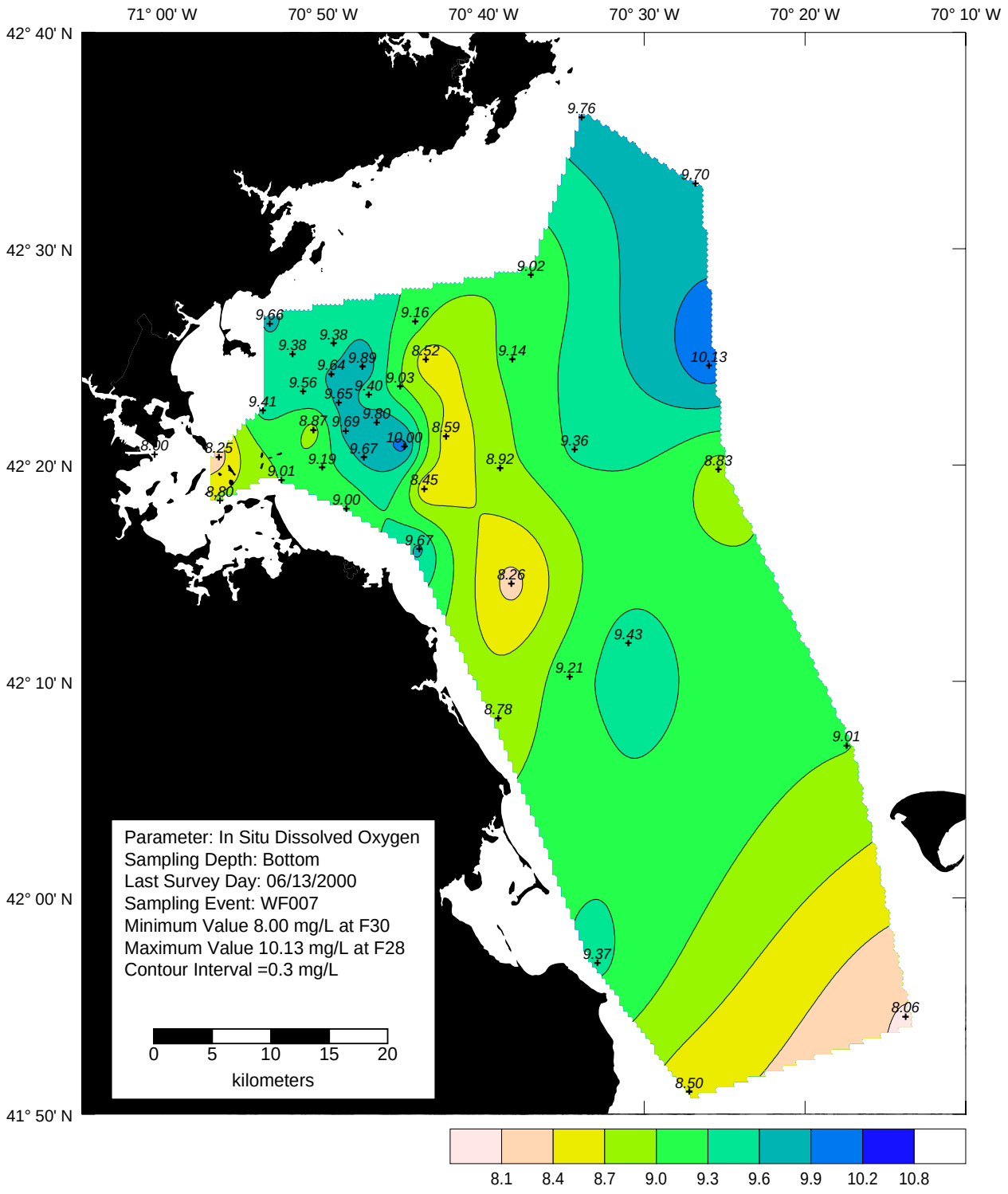


Figure 4-43. Bottom Water Dissolved Oxygen Contour Plot for Farfield Survey WF007 (Jun 00)

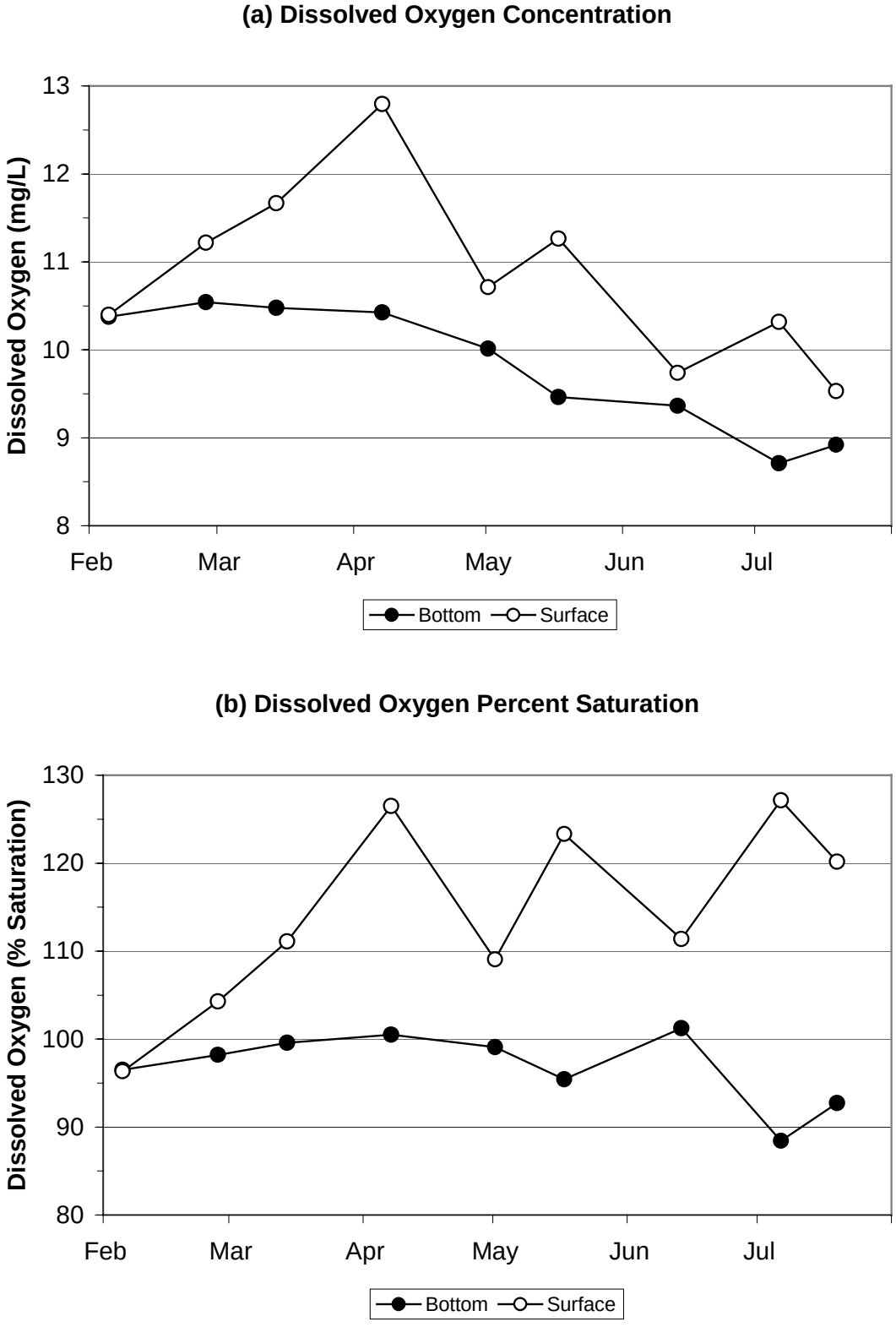


Figure 4-44. Time-Series of Bottom and Surface Average DO Concentration and Percentage Saturation in the Nearfield

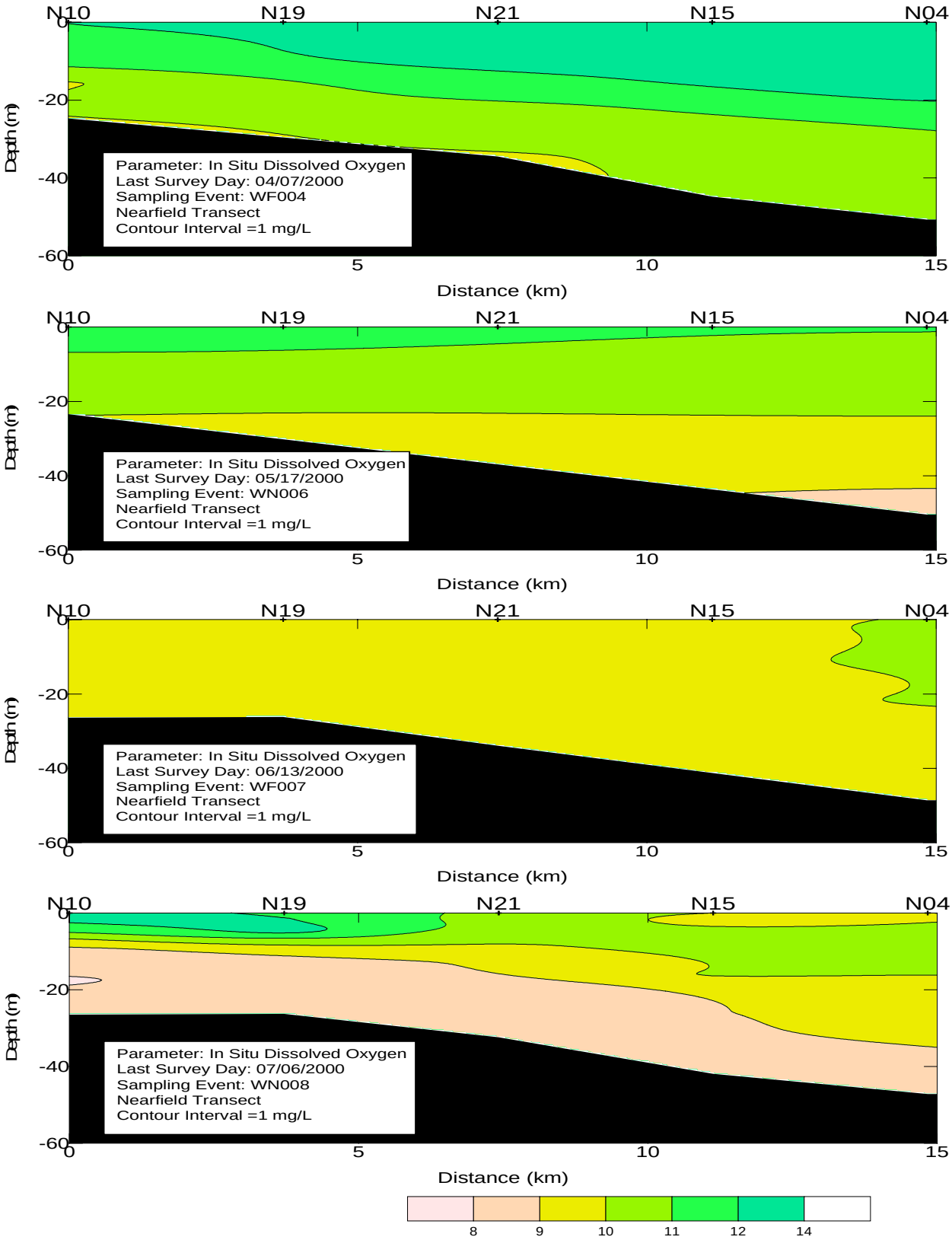


Figure 4-45. Dissolved Oxygen Vertical Nearfield Transects for Surveys WF004, WN006, WF007, and WN008

5.0 PRODUCTIVITY, RESPIRATION, AND PLANKTON RESULTS

5.1 Productivity

Production measurements were taken at two nearfield stations (N04 and N18) and one farfield station (F23) near the entrance of Boston Harbor. All three stations were sampled on February 3-4 (WF001), February 27 (WF002), April 1 (WF004) and June 8 (WF007). Stations N04 and N18 were additionally sampled on March 14 (WN003), May 1 (WN005), May 17 (WN006), July 6 (WN008), and July 19 (WN009). Samples were collected at five depths throughout the euphotic zone. Production was determined by measuring ^{14}C at varying light intensities as summarized below and in Appendix A.

In addition to samples collected from the water column, productivity calculations also utilized light attenuation data from a CTD-mounted 4π sensor, and incident light time-series data from a 2π irradiance sensor located on Deer Island, MA. After collection of the productivity samples, they were returned to the Marine Ecosystems Research Laboratory (MERL) in Rhode Island and incubated in temperature-controlled incubators. The resulting photosynthesis versus light intensity (P-I) curves (Figure 5-1 and comprehensively in Appendix E) were used, in combination with light attenuation and incident light information, to determine hourly production at 15-min intervals throughout the day for each sampling depth.

For this semi-annual report, areal production ($mgCm^{-2}d^{-1}$) and chlorophyll-specific areal production ($mgCmgChl\mathit{a}^{-1}d^{-1}$) are presented (Figures 5-2 and 5-3). Areal productions are determined by integrating measured productivity (and chlorophyll-specific productivity) over the depth interval. Chlorophyll-specific productivity for each depth was first determined by normalizing productivity by measured chlorophyll *a*. Productivity, chlorophyll *a* and chlorophyll-specific productivity for each depth are also presented as contour plots (Figures 5-4 to 5-9). As noted in Section 3.7, the chlorophyll and light data have been corrected, and we have used this new data in the calculation of production and chlorophyll-specific production presented in this section.

5.1.1 Areal Production

Areal production at the nearfield stations (N04 and N18) was similar throughout much of the semi-annual sampling period (Figure 5-2). Areal production at the two sites was relatively low (< 750 $mgCm^{-2}d^{-1}$) during the initial cruises on February 3 and February 27 (WF001 and WF002). Values increased at both sites to major production peaks by March 14 (WN003) and remained at elevated levels during the April 1 survey (WF004). At both stations the timing and extent of the winter-spring blooms in production were similar. The bloom peak at station N04 occurred on April 1 (WF004) with a peak production of 3118 $mgCm^{-2}d^{-1}$. Station N18 reached its maximum value (4269 $mgCm^{-2}d^{-1}$) somewhat earlier on March 14, but was characterized by elevated production (2780 $mgCm^{-2}d^{-1}$) on April 1. The peaks in production were coincident with the large *Phaeocystis* bloom that occurred in the bay in March/April (see Section 5.3).

Productivity decreased to levels <650 $mgCm^{-2}d^{-1}$ on May 1 (WN005) then increased to a minor peak on May 17 (WN006). The minor increase in production on May 17 occurred simultaneously at both stations and reached similar values of ~ 1500 $mgCm^{-2}d^{-1}$. Areal production declined at both stations N04 and N18 on June 8 (WF007). The productivity pattern at the nearfield sites diverged during July. At station N04 productivity increased from 1143 $mgCm^{-2}d^{-1}$ on July 6 (WN008) to 1555 $mgCm^{-2}d^{-1}$ on July 19 (WN009). At station N18 an elevated productivity of 4000 $mgCm^{-2}d^{-1}$ was observed on July 6 followed by a decrease in productivity to ~1000 $mgCm^{-2}d^{-1}$ on July 19.

The minimum production (~340 $mgCm^{-2}d^{-1}$) observed at station N04 was recorded on February 3, while the minimum at station N18 (480 $mgCm^{-2}d^{-1}$) was observed on May 1. The patterns observed at the nearfield sites were consistent with those observed during 1999 although the timing of events varied. The patterns were also consistent with patterns seen in chlorophyll distributions (Section 4.3).

Boston Harbor (station F23) displayed a different productivity pattern in comparison with the nearfield sites. At the Boston Harbor productivity/respiration station (F23), areal production was relatively low (~145 $mgCm^{-2}d^{-1}$) during the initial cruise (4 February). Areal production increased somewhat to ~500 $mgCm^{-2}d^{-1}$ by February 27 (WF002). Areal production reached a maximal value 4378 $mgCm^{-2}d^{-1}$ at station F23 during the April survey (WF004) then declined to moderate levels (~430 $mgCm^{-2}d^{-1}$) during the June survey (WF007). The production data are in agreement with the chlorophyll data through WF004. Elevated chlorophyll values during WF004 were associated with increased productivity levels and the *Phaeocystis* bloom. In June (WF007), chlorophyll values remained elevated at station F23, but rapid extinction of light with depth resulted in a reduced areal productivity measurement.

Areal production in 2000 followed patterns typically observed in prior years. A distinct winter-spring phytoplankton bloom was observed at both nearfield stations during the sampling period (Figure 5-2). In general, the nearfield is characterized by the occurrence of a winter-spring bloom. The winter-spring blooms observed at nearfield stations in 1995-1999 generally reached values of 1000 to 4000 $mgCm^{-2}d^{-1}$, with blooms typically lasting 2-3 months. The bloom in 2000 reached peak values of >2800 $mgCm^{-2}d^{-1}$ and lasted from March through April. The absence of a winter-spring phytoplankton bloom during 1998, a major change in the seasonal productivity pattern relative to other years for the nearfield region was not repeated in 1999 or 2000.

In general, the Boston Harbor site (station F23) exhibits a gradual pattern of increasing areal production from winter through summer rather than the distinct winter-spring peaks observed at the nearfield sites. In 2000 the pattern for station F23 did not conform to this description. Production values increased gradually from February through April, but decreased in June (Figure 5-2). During 1995-1999, peak areal productions at station F23 ranged from 2000 to 5000 $mgCm^{-2}d^{-1}$ in June-July. The peak areal production observed in 2000 occurred in April (4378 $mgCm^{-2}d^{-1}$) at station F23. Although the timing of events differed in 2000 the peak value observed at station F23 was similar to those seen in previous years. The earlier occurrence of peak production values in the harbor was likely due to the system wide *Phaeocystis* bloom that occurred in March and April of this year.

5.1.2 Chlorophyll-specific Areal Production

Chlorophyll-specific areal production was very similar at both nearfield sites (station N04 and N18) over time (Figure 5-3). Chlorophyll-specific areal production was relatively low (200-400 $mgCmgChl\mathit{a}^{-1}d^{-1}$) from February through mid-March. Chlorophyll-specific areal production increased at both stations by April 1 (WF004) to values of 725-890 $mgCmgChl\mathit{a}^{-1}d^{-1}$. Values decreased again during May then began a gradual climb to peak seasonal values at both stations on July 19 (WN009). Seasonal maxima at the nearfield sites were greater than 875 $mgCmgChl\mathit{a}^{-1}d^{-1}$. By comparison chlorophyll-specific rates in the harbor at station F23 did not exceed 540 $mgCmgChl\mathit{a}^{-1}d^{-1}$ throughout the sampling cycle (Figure 5-3). The peak chlorophyll-specific rate at station F23 did coincide in time with the initial peak observed at stations N04 and N18 on April 1, although at a lower rate.

Chlorophyll-specific production is an approximate measure for the efficiency of production and frequently reflects nutrient conditions at the sampling sites. The distribution of chlorophyll-specific

production indicates that the efficiency of production was high relative to the amount of biomass present at the nearfield stations. At both stations N04 and N18 the peak chlorophyll-specific production occurred well after the cessation of the winter-spring production peak. By contrast, efficiency of production was low at the harbor site relative to biomass availability.

5.1.3 Production at Specified Depths

The spatial and temporal distribution of production, chlorophyll and chlorophyll-specific production on a volumetric basis were summarized by showing contoured values over the sampling period (Figures 5-4 to 5-9). Chlorophyll-specific productions (daily production normalized to chlorophyll concentration at each depth) were calculated to compare production with chlorophyll concentrations. Chlorophyll-specific production can be used as an indicator of the optimal conditions necessary for photosynthesis.

The areal productivity peaks reported during March and early April at stations N04 and N18 were concentrated in the upper 10 m of the water column (Figures 5-4 and 5-5). At station N04, production was highest in the surface water on March 14 while a mid-surface productivity maximum was observed on April 1. At station N04 productivity tended to decrease following the spring peak values. At station N18, productivity also decreased following the spring phytoplankton bloom, but increased again in July. For station N04, the highest production value (205 $mgCm^{-3}d^{-1}$) occurred in the mid-surface waters (~9 m) on April 1. Peak production at station N18 during this period was about twice that observed at N04 and occurred in the surface and mid-surface waters (~2.5 - 6 m) waters on March 14. During the winter-spring period peak production values tended to be correlated with the occurrence of the highest chlorophyll *a* measurements (Figures 5-6 and 5-7).

Subsurface (5-11 m) productivity maxima were measured at station N18 (~530 mg C m^{-3} d^{-1}) and N04 (~ 75 mg C m^{-3} d^{-1}) on July 6 (WN008). Surface (~2 m) production maxima were observed at station N18 (~80 mg C m^{-3} d^{-1}) and N04 (~ 125 mg C m^{-3} d^{-1}) on July 19 (WN009; Figures 5-4 and 5-5). The productivity pattern at specified depths observed in 2000 was similar to that observed in prior years. At station N04 productivity as high as 30 mg C m^{-3} d^{-1} occurred to depths of 20 m. At station N18 productivity >20 mg m^{-3} d^{-1} was rarely observed at depths >20 m. Productivity in the harbor was largely restricted to the upper 10 m of the water column.

Chlorophyll-specific production at N04 and N18 was also concentrated in the upper portions of the water column (Figures 5-8 and 5-9). Chlorophyll-specific production increased throughout the sampling season reaching peak values during July at stations N04 and N18. The efficiency of photosynthesis increased as the season progressed. The increased chlorophyll-specific production observed during July at station N18 lead to elevated phytoplankton biomass (Figure 5-7). Interestingly, similarly high levels of chlorophyll-specific productivity during July at station N04 did not produce elevated phytoplankton biomass (Figure 5-6). When the efficiency of photosynthesis is high but not reflected in higher phytoplankton biomass (measured as total chlorophyll *a*) it suggests that other processes (such as predation by zooplankton) are important in controlling the patterns observed.

5.2 Respiration

Respiration measurements were made at the same nearfield (N04 and N18) and farfield (F23) stations as productivity and at an additional station in Stellwagen Basin (F19). All four stations were sampled during each of the combined farfield/nearfield surveys. Stations N04 and N18 were also sampled during the five nearfield only surveys. Respiration samples were collected from three depths (surface, mid-depth, and bottom) and were incubated in the dark at *in situ* temperatures for 8±1 days.

Both respiration (in units of $\mu MO_2\,hr^{-1}$) and carbon-specific respiration ($\mu MO_2\,\mu MC^{-1}\,hr^{-1}$) rates are presented in the following sections. Carbon-specific respiration was calculated by normalizing respiration rates to the coincident particulate organic carbon (POC) concentrations. Carbon-specific respiration rates provide a relative indication of the biological availability (labile) of the particulate organic material for microbial degradation.

5.2.1 Water Column Respiration

Due to an oversight, station F23 samples were left in the incubators for an extra day at room temperature in February (WF002) and there are only three sets of respiration data for this station. The data for the May survey (WN006) were also qualified as suspect because incubator temperatures increased to room temperature for at least 12 hours. These data are not included in the figures or discussion that follows.

During the surveys conducted in February (WF001 and WF002) and March (WN003), respiration rates were generally low in both the nearfield and farfield areas (<0.10 μMO_2hr^{-1}; Figures 5-10 and 5-11). By April (WF004), respiration rates had doubled in the nearfield (0.1 to 0.2 μMO_2hr^{-1}) and similar increases were observed at harbor station F23 and offshore station F19. Respiration rates were higher at station N04 in comparison to N18 and there was a clear difference in respiration rates over depth at station N04 with maximum rates in the surface waters (~0.2 μMO_2hr^{-1}). The increase in respiration rates in April was coincident with the winter-spring *Phaeocystis* bloom. The delay in peak production values at N04 versus N18 (April 1 versus March 14) likely contributed to the difference in respiration rates observed during WF004. At station N04, respiration rates were higher in the surface and mid-depth waters where the temperatures were warmer and higher rates of primary production were observed.

Respiration rates decreased from the April springtime highs to <0.10 μMO_2hr^{-1} in the nearfield in May (WN005) and remained relatively low in June (WF007). Surface water respiration rates were higher at both nearfield stations (0.12 – 0.14 μMO_2hr^{-1}). There was little change in the respiration rates measured at the two farfield stations from April to June. Respiration rates increased in the nearfield in July (WN008 and WN009). Rates at station N18 were higher and reached a maximum for the time period of 0.33 μMO_2hr^{-1} in the surface waters in early July (WN008). At station N18, the respiration rates remained >0.2 μMO_2hr^{-1} in the surface and mid-depth waters during both of the July surveys. Respiration rates were lower at station N04 and did not change substantially from June to early July. The station maximum for the time period was measured in the mid-depth waters in late July (~0.3 μMO_2hr^{-1}). Although both 1999 and 2000 had a significant winter/spring bloom, the respiration rates measured in 2000 were less than half of the peak rates measured in 1999 (Libby *et al.*, 1999). This will be explored in more detail in the annual water column report for 2000.

5.2.2 Carbon-Specific Respiration

Carbon-specific respiration accounts for the effect variations in the size of the particulate organic carbon (POC) pool have on respiration. Differences in carbon-specific respiration result from variations in the quality of the available particulate organic material or from environmental conditions such as temperature. Particulate organic material that is more easily degraded (more labile) will result in higher carbon-specific respiration. In general, newly produced organic material is the most labile. Water temperature is the main physical characteristic that controls the rate of microbial oxidation of organic material – the lower the temperature the lower the rate of oxidation. When stratified conditions exist, the productive, warmer surface and/or mid-depth waters usually exhibit higher carbon-specific respiration rates and bottom waters have lower carbon-specific respiration rates due to both lower water temperature and lower substrate quality due to the degradation of particulate organic material during sinking.

POC concentrations were relatively low (10-20 μMC) in the nearfield during the first two surveys and generally uniform over the water columns (Figure 5-12). In Boston Harbor (station F23), POC concentrations were similarly low in early February, but by the end of February the POC concentration in harbor surface waters had increased to ~55 μMC. By March (WN003), POC concentrations had increased to >40 μMC over the entire water column at station N18 and to ~30 μMC in surface and mid-depth waters at station N04. The carbon-specific respiration rates were low (usually <0.005 $\mu MO_2 \mu MC^{-1} hr^{-1}$) at all three stations during this time period (Figure 5-13).

In April (WF004), POC concentrations had increased at both nearfield stations to approximately 40 μMC (lower in the deeper bottom water at station N04). These elevated concentrations were coincident with the high chlorophyll concentrations and high production rates associated with the *Phaeocystis* bloom. There was a decrease in nearfield carbon-specific respiration rates, however, from February to April coincident with the increase in productivity and POC (Figure 5-12). At harbor station F23, POC concentrations remained higher than the nearfield concentrations in April (50-70 μMC). Carbon-specific respiration rates at station F23, however, were low throughout this period (≤ 0.005 $\mu MO_2 \mu MC^{-1} hr^{-1}$). The disconnect between carbon-specific respiration rates and productivity and the availability of newly formed POC plus the relatively low respiration rates observed the winter/spring of 2000 versus 1999 may be related to the type of phytoplankton that bloomed in 2000 (*Phaeocystis* versus a mixed diatom assemblage). This will be examined in more detail in the 2000 Nutrient Issues Review.

POC concentrations decreased to ~20 μMC at the nearfield stations by early May (WN005) coincident with decreases in chlorophyll concentration and production rates. By mid-May, POC concentrations had increased to levels slightly higher than those observed during the March/April bloom (40-55 μMC). Low concentrations (~20 μMC) were again measured at station N18 in June. Surface water POC concentrations remained elevated at station N04 from June thru July (~30 μMC). Maximum nearfield POC concentrations were measured in the surface and mid-depth waters at station N18 in early July (80 μMC). In Boston Harbor, POC concentrations remained high from April to June (60-80μMC). Overall, carbon-specific respiration in the harbor and nearfield was relatively low during this time period. The only time carbon specific respiration exceeded 0.01 $\mu MO_2 \mu MC^{-1} hr^{-1}$ was in the bottom waters at station N04 in late July. These low numbers suggest that there were limited supplies of labile POC available during the winter/spring of 2000 despite the fact that there was a very substantial *Phaeocystis* bloom (see Section 5.3).

5.3 Plankton Results

Plankton samples were collected on each of the nine surveys conducted during this reporting period. Phytoplankton and zooplankton samples were collected at two stations during each nearfield survey (N04 and N18) and at 11 farfield and the two nearfield stations (total = 13) during the farfield surveys. Two additional stations were sampled for zooplankton in Cape Cod Bay (F32 and F33) during the first three farfield surveys (WF001, WF002 and WF004), but not during the fourth (WF007). Also, two additional "upstream" stations (F22 and F26) were sampled for phytoplankton and zooplankton during WF004 and WF007, but not during WF001 and WF002. These two stations (F22 and F26) will continue to be sampled on a regular basis during all farfield surveys. Phytoplankton samples included both whole-water and 20 μm-mesh screened samples, from the surface and subsurface chlorophyll maximum depths. Zooplankton samples were collected by vertical/oblique tows with 102 μm-mesh nets. Methods of sample collection and analyses are detailed in Albro *et al*. (1998).

In this section, the seasonal trends in plankton abundance and regional characteristics of the plankton assemblages are evaluated. Total abundance and relative abundances of major taxonomic groups are presented for each phytoplankton and zooplankton community. Tables in the appendices provide data on cell and animal densities and relative abundance for all dominant plankton species (>5% abundance): Appendix F – whole water phytoplankton, Appendix G – 20-µm screened phytoplankton, and Appendix H – zooplankton.

5.3.1 Phytoplankton

5.3.1.1 Seasonal Trends in Total Phytoplankton Abundance

Total phytoplankton abundances in nearfield whole water samples (surface and mid-depth) were variable from February through July (Table 5-1). Total abundances were low and varied between approximately 0.13 –2.27 x 10^6 cells L^{-1} in February-early March. However, abundances increased dramatically in late March and April (WF004) to levels of 2.52-11.01 x 10^6 cells L^{-1} during a bloom of *Phaeocystis pouchetii*. Abundances declined thereafter to levels of 0.19-3.66 x 10^6 cells L^{-1} in May – July (WN005-WN009). Total abundances at the surface at stations N04, N16 and N18 (Figure 5-14) were generally < 2-4 x 10^6 cells L^{-1} for all taxa except *Phaeocystis* (labeled as "Other" in these figures), with abundances for *Phaeocystis* scaling total phytoplankton abundances on the ordinates of these figures to maxima of 7 x 10^6 cells L^{-1}. Total abundances at mid-depth for all taxa except *Phaeocystis* were similarly low, < 2 - 4 x 10^6 cells L^{-1} for these same nearfield stations (Figure 5-15), but *Phaeocystis* abundance during WF004 scaled total abundances for these figures to 12.0 x 10^6 cells L^{-1}.

Total phytoplankton abundance in farfield whole water samples (surface and mid-depth) showed similar low abundances in February with levels generally < 0.81 x 10^6 cells L^{-1} during survey WF001 (Table 5-1 and Figure 5-16), and values between 0.14 –1.5 x 10^6 cells L^{-1} during survey WF002 (Figure 5-17). By early April (WF004) farfield abundances jumped to 1.39-13.76 x 10^6 cells L^{-1} throughout the survey area during the bloom of *Phaeocystis* (Figure 5-18). As in the nearfield, *Phaeocystis* concentrations were generally higher at the mid-depth compared to the surface waters. By June (WF007) phytoplankton abundances had declined, back to pre-*Phaeocystis*-bloom levels of < 3.38 x 10^6 cells L^{-1} at all stations (Table 5-1), and levels < 1-2 x 10^6 cells L^{-1} at most stations (Figure 5-19).

Total abundances of dinoflagellates, silicoflagellates and protozoans in 20 µm-mesh-screened water samples were considerably lower than those recorded for total phytoplankton in whole-water samples, due to the screening technique which selects for larger, albeit rarer cells. Dinoflagellates and silicoflagellates in nearfield and farfield screened phytoplankton samples were generally < 10^3 cells L^{-1} from February through early March, decreased to < 0.5 x 10^3 cells L^{-1} during the April *Phaeocystis* bloom, rebounding to values as high as > 16.6 x 10^3 cells L^{-1} by late July (Table 5-2).

Table 5-1. Nearfield and Farfield Averages and Ranges of Abundance (10^6 Cells L^{-1}) of Whole-Water Phytoplankton

Survey	Dates (2000)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF001	2/2-5	0.45	0.30-0.68	0.47	0.24-0.81
WF002	2/23-25,27	0.22	0.13-0.38	0.67	0.14-1.50
WN003	3/14	2.10	1.89-2.27	NA	NA
WF004	3/30,4/1,3,7	6.81	2.52-11.01	6.82	1.39-13.76
WN005	5/1	0.67	0.19-1.00	NA	NA
WN006	5/17	2.29	2.07-2.52	NA	NA
WF007	6/8,9,13	1.18	0.73-1.50	1.54	0.31-3.38
WN008	7/6	2.15	0.55-3.66	NA	NA
WN009	7/19	2.27	1.53-3.05	NA	NA

NA- Data not available because the farfield stations were not sampled during this survey.

Table 5-2. Nearfield and Farfield Average and Ranges of Abundance (Cells L^{-1}) for >20 µM-Screened Phytoplankton

Survey	Dates (2000)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF001	2/2-5	891	660-1040	886	229-3160
WF002	2/23-25,27	253	187-403	147	36-370
WN003	3/14	315	212-394	NA	NA
WF004	3/30,4/1,3,7	100	28-205	157	34-444
WN005	5/1	383	290-500	NA	NA
WN006	5/17	4362	3833-5363	NA	NA
WF007	6/8,9,13	2692	1576-3428	1860	162-3682
WN008	7/6	1905	1214-2661	NA	NA
WN009	7/19	7638	2607-16637	NA	NA

NA- Data not available because the farfield stations were not sampled during this survey.

5.3.1.2 Nearfield Phytoplankton Community Structure

Whole-Water Phytoplankton – In February (WF001and WF002), nearfield whole-water phytoplankton assemblages from both depths were dominated by unidentified microflagellates < 10 µm in diameter, cryptomonads, centric diatoms such as *Thalassiosira* spp. 10 - 20 µm in diameter and unidentified centric diatoms < 10 µm in diameter, probably also a species of *Thalassiosira* (Figures 5-14 and 5-15). Beginning in March (WN003) and particularly in April (WF004), *Phaeocystis pouchetii* became dominant, comprising > 50% of total cells in March, increasing to > 90% of total cells in April. Microflagellates remained at similar abundances to levels in February, but the centric diatoms recorded for February, along with *Thalassiosira nordenskioldii* actually declined in abundance from March through April. By May (WN005) *Phaeocystis* had disappeared, and from May through July there was increasing abundance and dominance of microflagellates < 10 µm in diameter, cryptomonads, and centric diatoms such as *Skeletonema costatum, Guinardia delicatula, Thalassiosira* sp. in June, joined by the centric diatoms *Dactyliosolen fragilissimus* and *Leptocylindrus minimus* in July (WN008). Also in May through July the dinoflagellates *Gymnodinium* sp. and *Prorocentrum minimum* increased in abundance.

Screened Phytoplankton - In early February (WF001), nearfield screened samples were dominated by the thecate dinoflagellate *Prorocentrum micans*, which comprised 50-91% of cells counted. There were lesser contributions from the dinoflagellates *Ceratium fusus* and *C. tripos*, and the silicoflagellates *Distephanus speculum* and *Dictyocha fibula.* These same taxa dominated during late February (WF002) although *Distephanus speculum* had increased to 18-46% of cells counted. In March (WN003), these same taxa were abundant in varying proportions, with increases in the two *Ceratium* species to levels of up to 26-35% of cells counted. The same taxa were abundant in April (WF004) with additions of *Ceratium longipes, C. macoceros, Gymnodinium* spp. *Prorocentrum minimum* and *Protoperidinium* spp..

By early May (WN005), *Ceratium longipes* comprised approximately 60-80% of cells counted, with lesser contributions by *C. fusus, C. tripos*, and *Prorocentrum minimum*. These taxa were joined in late May (WN006) by *Ceratium lineatum* and *Dinophysis norvegica*. In June (WF007) there was continued dominance by *C. fusus, C. lineatum, C. longipes* and *C. tripos*, and to a lesser extent, *Dinophysis norvegica* and *Prorocentrum minimum*. The *Ceratium* quartet continued to dominate in July (WN008 and WN009) with subdominant abundance by *D. norvegica*.

5.3.1.3 Regional Phytoplankton Assemblages

Whole-Water Phytoplankton - Whole-water phytoplankton assemblages at farfield stations were generally similar to those in the nearfield during the same time periods, in terms of composition, abundance, and the major *Phaeocystis* bloom in April.

During February (WF001 and WF002), most farfield station assemblages were dominated at both depths by the same assemblages that dominated nearfield stations. These included unidentified microflagellates, cryptomonads, and diatoms of the genus *Thalassiosira* (Fig. 5-16 and 5-17). An unidentified species of the dinoflagellate genus *Gymnodinium* was recorded at abundances of approximately 5-10% of total cells at several stations.

In April (WF004), most farfield stations were overwhelmingly dominated by *Phaeocystis pouchetii* (Fig. 5-18) with comparatively minor contributions by unidentified microflagellates and the same assemblage of diatoms recorded for February. The *Phaeocystis* bloom occurred in Cape Cod Bay, but not in as overwhelming numbers as in Massachusetts Bay.

By June (WF007), assemblages at both depths at most farfield stations were dominated by the same microflagellates and cryptomonads that dominated the nearfield, with subdominant contributions by the same diatom taxa recorded for the nearfield during this period (*Skeletonema costatum, Thalassiosira* spp.).

Screened Phytoplankton - Screened-water dinoflagellate assemblages at farfield stations were similar to those in the nearfield during the same time periods.

In February (WF001 and WF002), 20 µm-screened surface phytoplankton samples from the farfield were dominated by *Prorocentrum micans* and *Distephanus speculum*, as in the nearfield, although *Prorocentrum minimum* comprised 70% of cells counted at the surface at F25 during WF001.

In April (WF004), farfield assemblages were dominated by *Ceratium tripos, C. fusus*, and *C. longipes*, the silicoflagellates *Distephanus speculum* and *Dictyocha fibula* with lesser contributions by *Prorocentrum minimum* and *Protoperidinium* spp. at some stations. At stations F23 and F30 in Boston Harbor, the dinoflagellate *Gyrodinium spirale* comprised up to 37 - 65% of total cells

counted, and the photosynthetic ciliate *Mesodinium rubrum* comprised 12-55% of total cells counted at several other stations.

Screened farfield samples in June (WF007) were dominated by the same assemblages as in the nearfield, including species of the dinoflagellate genus *Ceratium* (*fusus, lineatum, longipes, tripos*), *Dinophysis norvegica* and *Prorocentrum minimum*.

5.3.1.4 Nuisance Algae

The major bloom of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during February – July 2000 was the April bloom of *Phaeocystis pouchetii*. At cell concentrations of 0.233-12.258 x 10^6 cells L^{-1} (mean = 6.2 x 10^6 cells L^{-1}) it was the major phytoplankton event of the period. Also, comparison of mean abundances of *Phaeocystis* from the nearfield in 2000 with those of previous "*Phaeocystis*" years such as 1992, 1994, and 1997 (Figure 5-20) reveals that this species appears to bloom in 3-4 year cycles, and that levels in spring of 2000 were higher than those recorded for any previous years since monitoring began in 1992.

The toxic dinoflagellate *Alexandrium tamarense* was only sporadically recorded. There were a few occurrences of "*Alexandrium* spp." in screened samples that were not positively identified as *A. tamarense*. These included single occurrences in February (WF001) and March (WN003), at abundances of 1.5 cells L^{-1}, twice in April (WF004) at abundances of 3.0 – 3.1 cells L^{-1}, at 3 stations during the June survey (WF007) at abundances of 1.8 – 1.9 cells L^{-1}, and at one station in July (WN009) at an abundance of 20.7 cells L^{-1}. Abundance of *Alexandrium tamarense* plus *Alexandrium* spp. in screened samples in 2000 was typically low, as evidenced by mean abundance in the nearfield compared to previous years (Figure 5-21). Levels since 1994 have not approached those of 1993.

Pseudo-nitzschia pungens or *Pseudo-nitzschia* spp. were also found sporadically. In early February (WF001), *Pseudo-nitzschia* spp. cells were seen in 7 whole water samples at trace amounts (hundreds of cells L^{-1}). During the April survey (WF004), *Pseudo-nitzschia* spp. cells were found at station N04, at an abundance of 300 cells L^{-1}. At stations F23 and F24 in June (WF007), a single cell of the potentially toxic species *Pseudo-nitzschia delicatissima* was recorded at each station for abundances of 400 cells L^{-1}.

Abundance of *Pseudo-nitzschia* in 2000 was lower than that recorded in most previous years (Figure 5-22). Due to inconsistent characterization of *Pseudo-nitzschia pungens, Pseudo-nitzschia* cf. *Pungens,* and *Pseudo-nitzschia* sp. in different years over the course of the baseline period, records for all these categories were combined in the baseline figure. In Figure 5-22, it is clear that *Pseudo-nitzschi*a abundance has been much higher in some previous years than in the first half of 2000, and that *Pseudo-nitzschia* usually only becomes abundant in the fall and winter rather than in the spring and summer.

5.3.2 Zooplankton

5.3.2.1 Seasonal Trends in Total Zooplankton Abundance

Total zooplankton abundance at nearfield stations generally increased from February through July (WF001-WN009; Figure 5-23). The maximum nearfield values of 146-290 x 10^3 animals m^{-3} recorded in June and July (WF007, WN008 and WN009; Table 5-3) were among the highest during the entire 1992-2000 baseline period.

Total zooplankton abundance at farfield stations in February was low (< 20 x 10^3 animals m^{-3} for WF001 and < 30 x 10^3 animals m^{-3} for WF002; Figure 5-24). By April (WF004), total zooplankton abundance at farfield stations had increased slightly, with values at two of the stations of

> 30 x 10^3 animals m^{-3}, but most were < 10 x 10^3 animals m^{-3} (Figure 5-25a). The spring-summer increase in farfield zooplankton abundance jumped by June (WF007), from all values < 50 x 10^3 animals m^{-3} in April to all but one value >50 x 10^3 animals m^{-3} and 7 of 15 values >100 x 10^3 animals m^{-3} in June (Figure 5-25b).

Table 5-3. Nearfield and Farfield Average and Ranges of Abundance (10^3 Animals m^{-3}) for Zooplankton

Survey	Dates (2000)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF001	2/2-5	12.8	7.6-16.5	8.1	0.9-16.5
WF002	2/23-25,27	14.5	8.2-19.3	15.4	5.0-29.2
WN003	3/14	26.9	13.0-40.9	NA	NA
WF004	3/30, 4/1,3,7	10.2	6.2-12.6	15.5	3.6-45.9
WN005	5/1	31.1	15.8-46.3	NA	NA
WN006	5/17	55.4	36.2-74.5	NA	NA
WF007	6/8,9,13	139.3	59.4-289.8	108.0	30.4-187.0
WN008	7/6	115.2	84.4-146.1	NA	NA
WN009	7/19	274.4	273.9-274.9	NA	NA

NA- Data not available because the farfield stations were not sampled during this survey.

5.3.2.2 Nearfield Zooplankton Community Structure

During early February (WF001), the nearfield zooplankton assemblages (Figure 5-23) were dominated by copepod nauplii (27-32%), as well as copepodites of *Oithona similis* (21-32%) and *Pseudocalanus* spp. (up to 23%). In late February (WF002), the same patterns occurred with dominance by copepod nauplii (36-45%) and *Oithona similis* (16-28%) and *Pseudocalanus* spp. (6-24%) copepodites. A similar assortment was also found in March (WN003) with nearfield dominance by copepod nauplii (46-68%) and *Oithona similis* copepodites (23-46%).

At nearfield stations during April (WF004), zooplankton assemblages were dominated by copepod nauplii (34-36%) and copepodites of *Oithona similis* (23-26%) and *Calanus finmarchicus* (8-15%) and barnacle nauplii (7-11%). In May, during WN005 and WN006, nearfield zooplankton assemblages continued to be dominated by the combination of copepod nauplii (25-28%), copepodites of *Oithona similis* (6-12% and 16-32%, during WN005 and WN006, respectively) and *Pseudocalanus* spp. (up to 6-7%). However, during WN005 *Calanus finmarchicus* copepodites comprised 28-43% and during WN006, bivalve veligers were 7-33% of total abundance.

At nearfield stations during June (WF007), zooplankton assemblages were dominated by bivalve veligers (7-64%), copepodites of *Oithona similis* (13-17%), *Centropages* spp. (6-14%), *Calanus finmarchicus* (up to 13%) and copepod nauplii (17-47%). In Figure 5-23, the disparity between total zooplankton abundance between nearfield stations N04 and N18, which were sampled on June 8th, and station N16, where the zooplankton sample was collected on June 9th, is due to the very high abundance of bivalve veligers (as "other" in Figure 5-25) at station N16. This is indicative of the biological (spawning) and physical (tides and currents) variability associated with meroplankton abundances and distribution in Massachusetts Bay. Subtracting the bivalve veliger abundance from total abundance at station N16, the total non-veliger abundance was 103.8 x 10^3 animals m^{-3}, which is closer to the total abundances of 59.4 and 68.6 x 10^3 animals m^{-3} at the other nearfield stations. Also, abundances of other major taxa were reasonably close, with values for copepod nauplii of 24.96, 27.97, and 49.29 x 10^3 animals m^{-3}, and for Oithona similis copepodites of 8.78, 9.92, and 13.34 x 10^3 animals m^{-3} at stations N04, N18, and N16, respectively.

Dominance by copepodites and females of *Oithona similis* and *Pseudocalanus* spp. and copepod nauplii continued through July (WN008 and WN009), with the contribution of bivalve veligers declining to 27-38%. During both July surveys, *Temora longicornis* copepodites comprised 7-10% of total abundance at station N04.

5.3.2.3 Regional Zooplankton Assemblages

Zooplankton assemblages at farfield stations during early February (WF001) were generally similar to those in the nearfield (Figure 5-24). Abundant taxa throughout the area included copepod nauplii (28-60%) and *Oithona similis* copepodites and females (9-45%). Copepodites of *Pseudocalanus* spp. and *Centropages* spp. were present at most stations, comprising 6-23% of total abundance. In late February (WF002), dominance by copepod nauplii (26-67%) and *Oithona similis* copepodites and females (8-38%) continued throughout the study area, as did abundance of copepodites and adults of *Pseudocalanus* spp. (7-33%) and *Centropages* spp. (6-14%) at most stations. Barnacle nauplii comprised 15% and 48%, respectively, at stations F30 and F31 in Boston Harbor.

In April (WF004; Figure 5-25), copepod nauplii were dominant at all farfield stations (6-53%), as were *Oithona similis* copepodites (9-34%) at all stations except station F30 and F31 in Boston Harbor. *Pseudocalanus* spp. copepodites comprised up to 6-54% of abundance at all but three stations, two of which were in Boston Harbor. *Calanus finmarchicus* comprised 10-11% of abundance at stations F02 and F32 in Cape Cod Bay. Barnacle nauplii reached as high as 64% of total abundance at stations where present, and polychaete larvae were 13-70% of abundance at stations F23, F30 and F31 in Boston Harbor.

During June (WF007), farfield zooplankton assemblages were again dominated by copepod nauplii (17-50%), copepodites of *Oithona similis* (5-40%), and *Pseudocalanus* spp. (up to 12% at stations where present). Bivalve veligers accounted for up to 49% of abundance at most stations where they were present. *Acartia* spp. adults and copepodites accounted for 22%, 21%, and 6% of total abundance at stations F23, F30, and F31, respectively, in Boston Harbor. Also, *Eurytemora herdmani* adults and copepodites, typically found in low-salinity embayments, comprised 8-10% of abundance at stations F23 and F30 in Boston Harbor. Unlike the abnormally low abundance of *Acartia* spp. during drought conditions during the early part of 1999, *Acartia* abundance in Boston Harbor rebounded to more typical levels during the rainy spring and summer in 2000.

In summary, zooplankton assemblages during the first half of 2000 were comprised of taxa typically recorded for the same time of year in previous years.

5.4 Summary of Production, Respiration and Plankton Results

- There was a system-wide major bloom of *Phaeocystis pouchetii* in April with abundance levels approaching 14 million cells per liter.
- Peaks in production were coincident with the large *Phaeocystis* bloom that occurred in the bay in March/April 2000. At station N18, production reached a maximum value on March 14 (4269 $mgCm^{-2}d^{-1}$) and remained elevated in April (2780 $mgCm^{-2}d^{-1}$). The peak at station N04 occurred on April 1 (3118 $mgCm^{-2}d^{-1}$).
- The productivity peaks reported during March and early April at stations N04 and N18 were concentrated in the upper 10 m of the water column.
- Areal production in 2000 followed patterns typically observed in prior years – a winter-spring bloom at nearfield stations with production rates of 1000 to 4000 $mgCm^{-2}d^{-1}$ that typically last 2-3 months.

- The Boston Harbor station (F23) usually exhibits a pattern of increasing production from winter through summer rather than the distinct winter-spring peaks observed in the nearfield. In 2000, this was not the case as peak production at station F23 occurred in April (4378 $mgCm^{-2}d^{-1}$). The earlier occurrence of peak production values in the harbor was likely due to the system wide *Phaeocystis* bloom that occurred in March and April.
- Respiration rates increased in April coincident with the winter-spring *Phaeocystis* bloom. Maximum nearfield respiration rates were measured in July (~0.30 μMO_2hr^{-1}). Although both 1999 and 2000 had significant winter/spring blooms, the respiration rates measured in 2000 were less than half of the peak rates measured in 1999.
- Elevated POC concentrations were coincident with the high chlorophyll concentrations and high production rates associated with the *Phaeocystis* bloom in the nearfield and harbor. Carbon-specific respiration rates, however, were low throughout this period ($\leq 0.01 \mu MO_2\mu MC^{-1}hr^{-1}$).
- The relatively low respiration rates and the disconnect between carbon-specific respiration rates and productivity observed during the winter/spring of 2000 versus 1999 may be related to the type of phytoplankton that bloomed in 2000 versus 1999 (*Phaeocystis* versus a mixed diatom assemblage).
- Whole-water phytoplankton assemblages were dominated by unidentified microflagellates and several species of centric diatoms except during the *Phaeocystis* bloom. This is typical for the first half of the year in terms of taxonomic composition.
- As in previous years, screened phytoplankton samples evidenced a bloom of *Ceratium furca /C. tripos/* C. *longipes* which exhibited general increases from February through July.
- There were no blooms of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during February – July, 2000, other than the April bloom of *Phaeocystis pouchetii*. While the dinoflagellate *Alexandrium tamarense* and diatoms of *Pseudo-nitzschia pungens* and *Pseudo-nitzschia* spp. were recorded in trace amounts, abundance levels were extremely low.
- Total zooplankton abundance generally increased from February through July. Nearfield counts of nearly 300 x 10^3 animals m^{-3} during WF007 were among the highest for the entire 1992-2000 baseline period.
- Zooplankton assemblages during the first half of 2000 were comprised of taxa recorded for the same time of year in previous years, but levels of *Acartia* spp. rebounded from the unusually low values of the previous year, which were possibly due to drought, to more typical levels during a rainy spring and early summer.

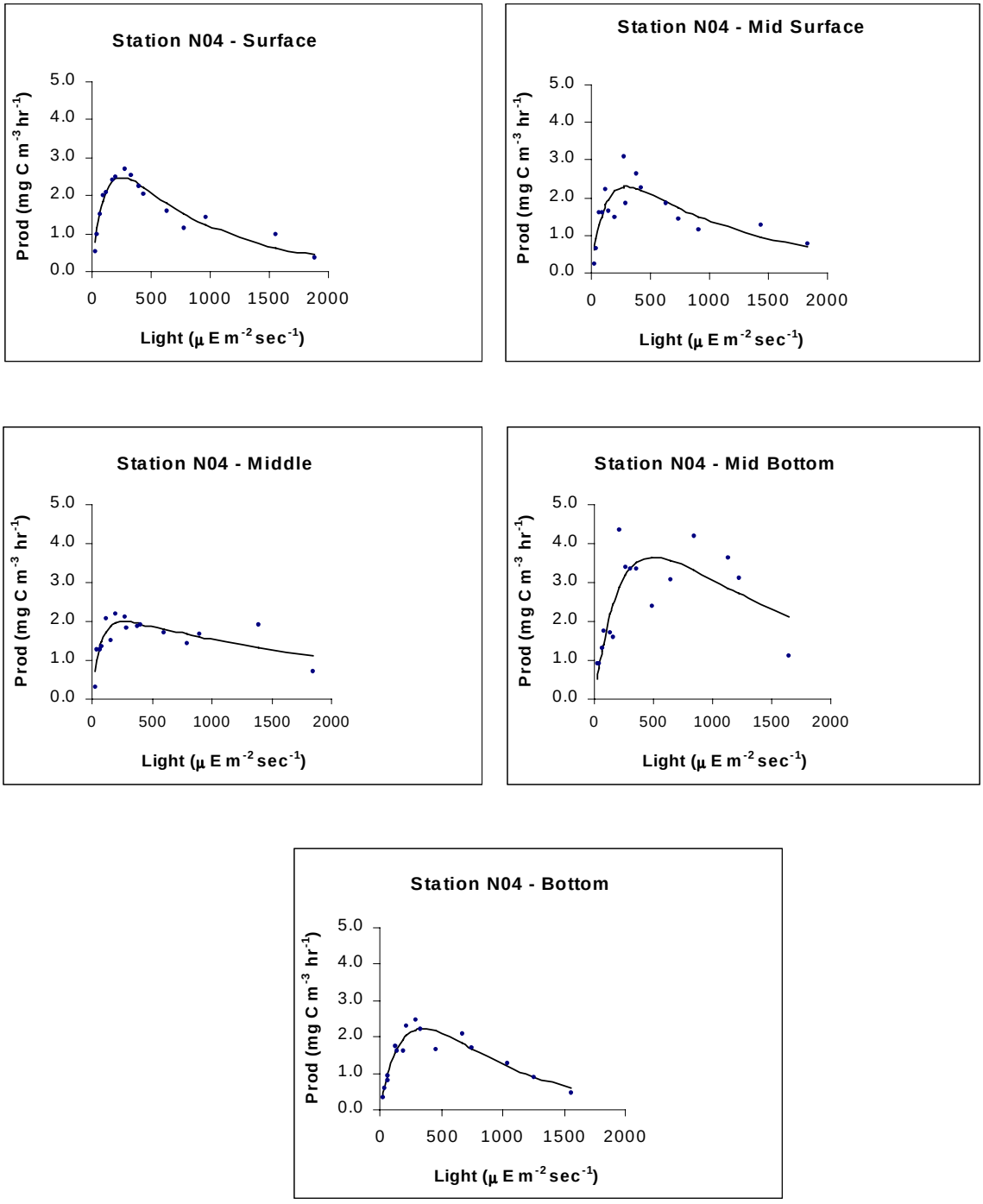


Figure 5-1. An Example Photosynthesis-Irradiance Curve From Station N04 Collected in February 2000

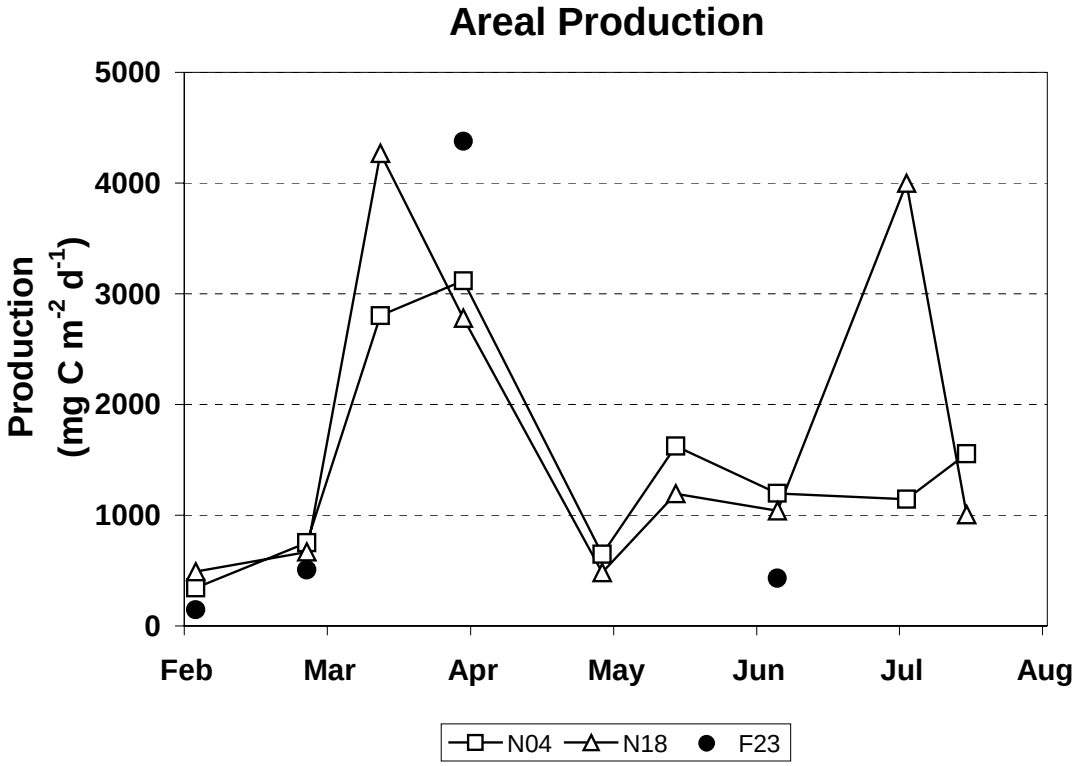


Figure 5-2. Time-Series of Areal Production ($mgCm^{-2}d^{-1}$) for Productivity Stations

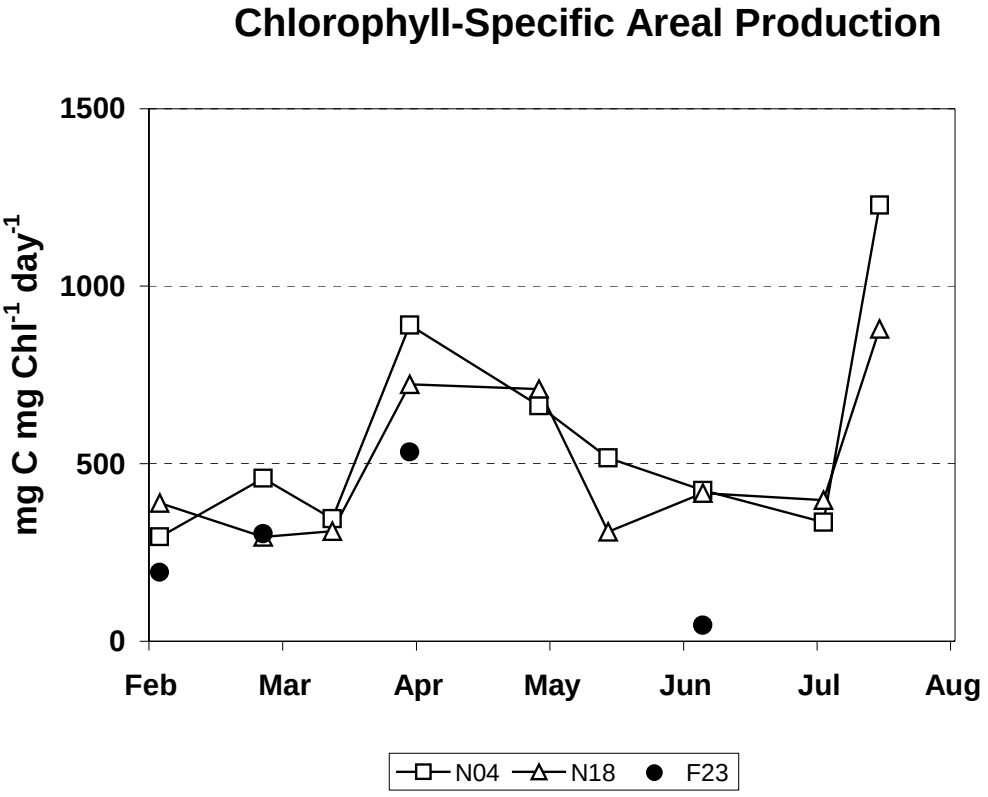


Figure 5-3. Time-Series of Chlorophyll-Specific Areal Production (mgCmgChl*a*$^{-1}$d^{-1}) for Productivity Stations

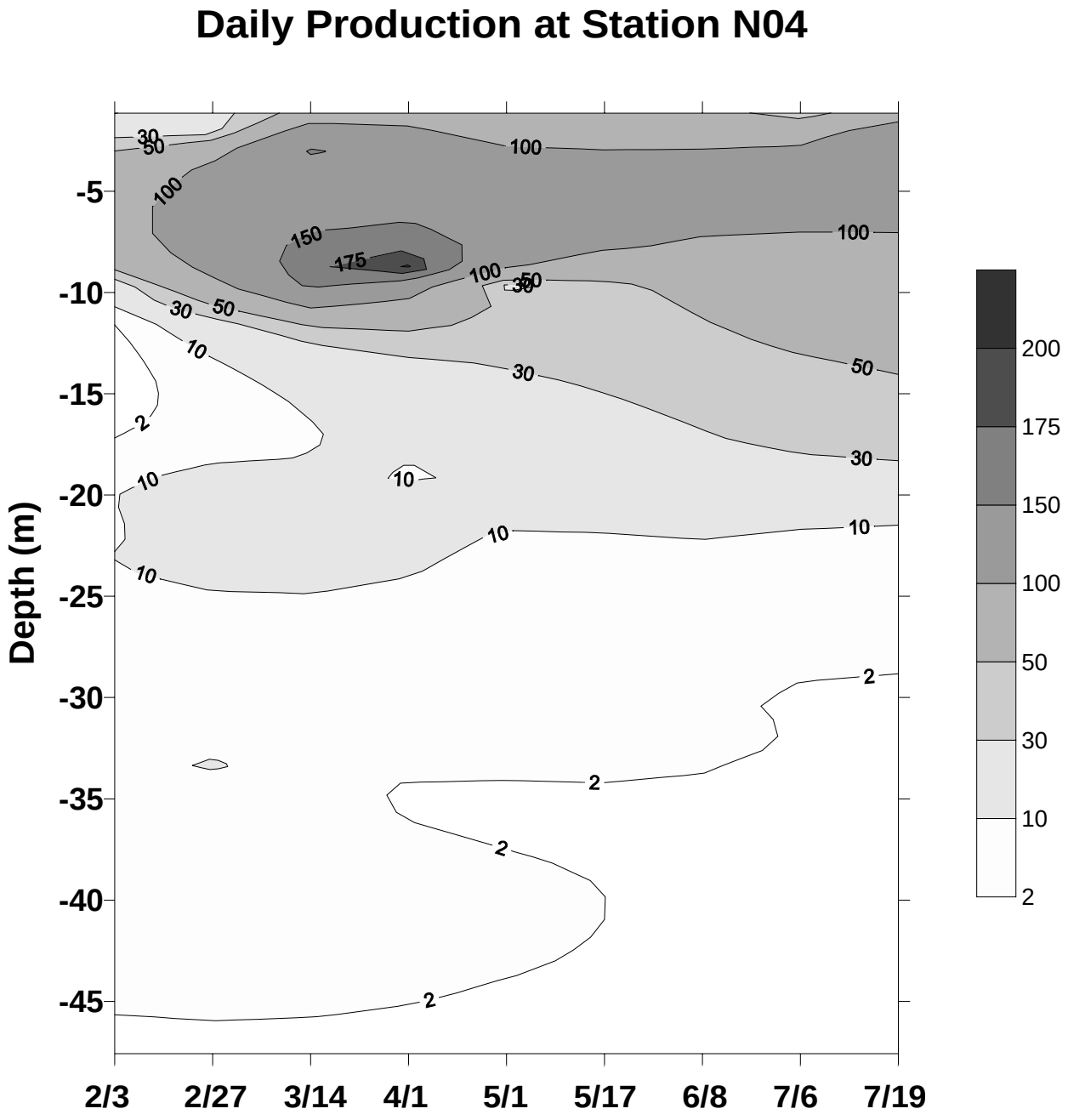


Figure 5-4. Time-Series of Contoured Daily Production ($mgCm^{-3}d^{-1}$) Over Depth at Station N04

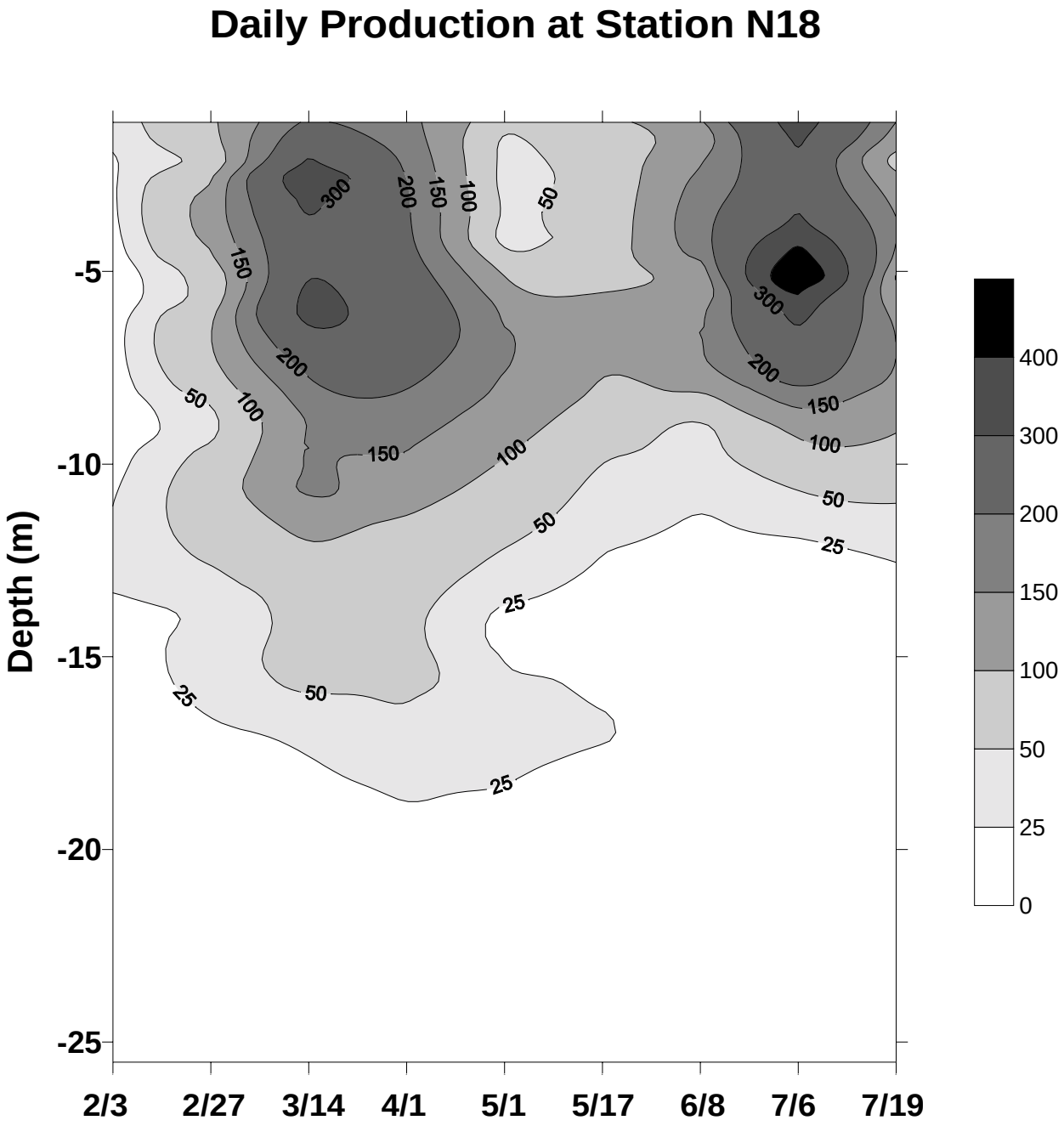


Figure 5-5. Time-Series of Contoured Daily Production ($mgCm^{-3}d^{-1}$) Over Depth at Station N18

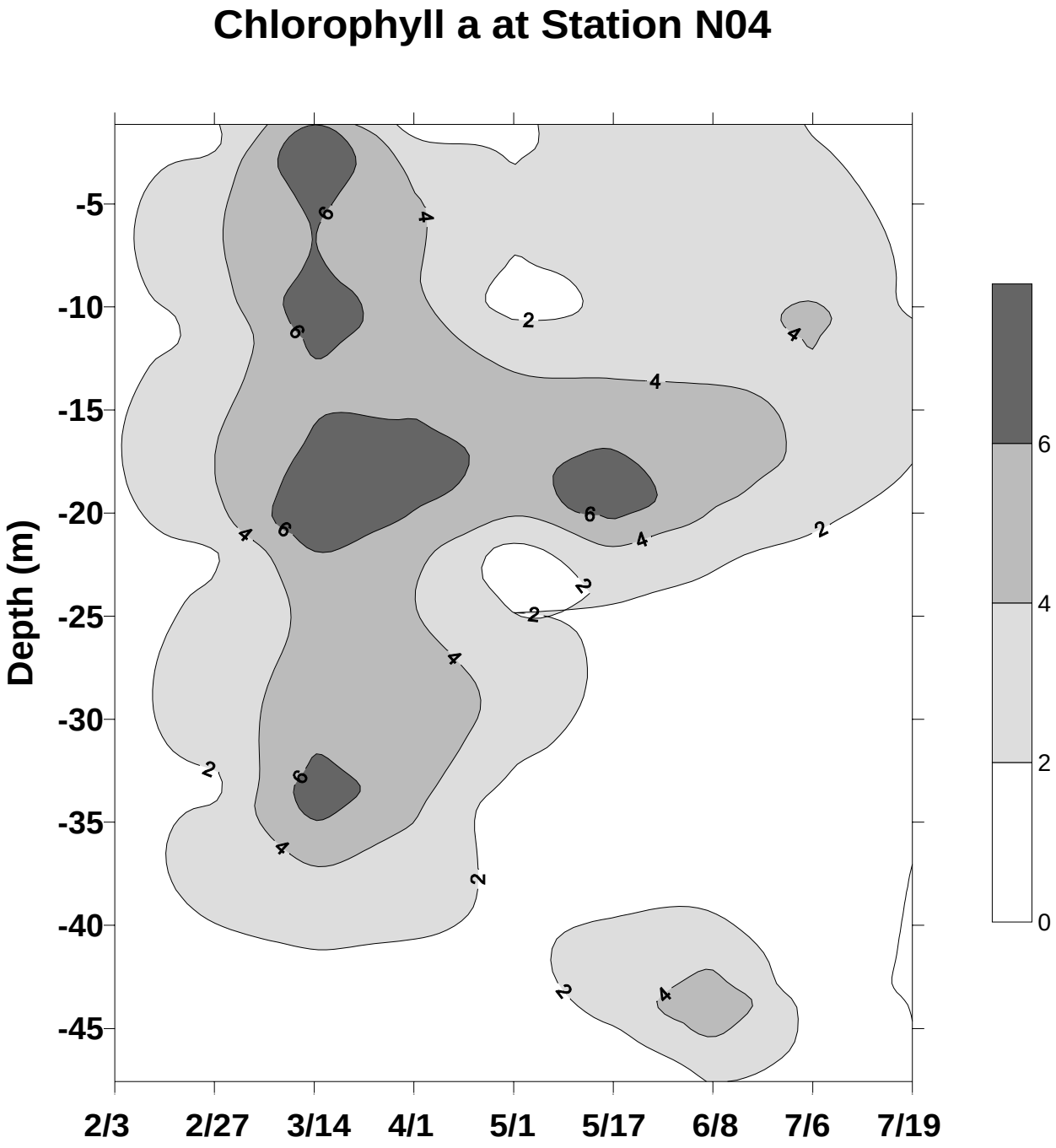


Figure 5-6. Time-Series of Contoured Chlorophyll *a* Concentration (μgL^{-1}) Over Depth at Station N04

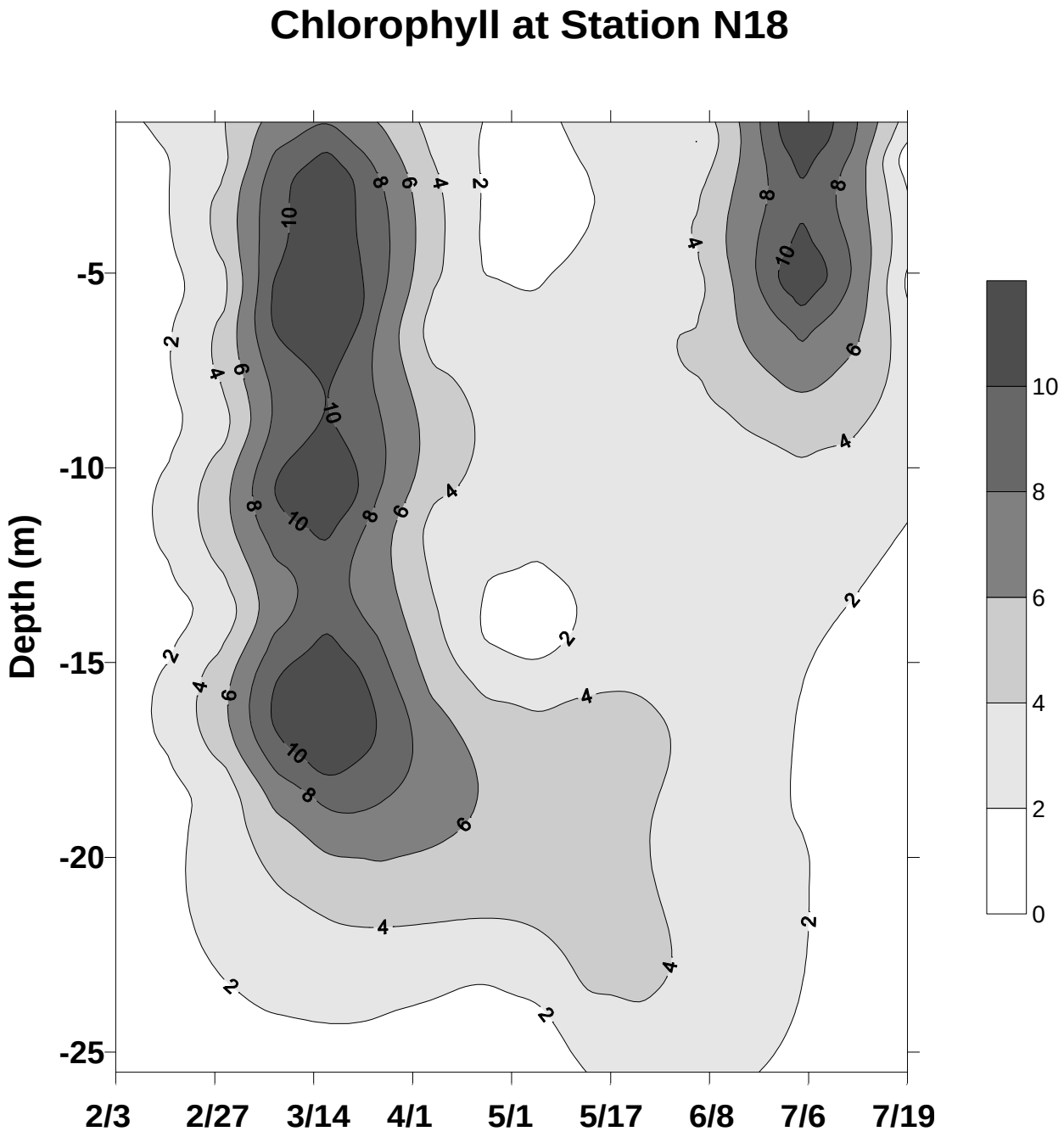


Figure 5-7. Time-Series of Contoured Chlorophyll *a* Concentration (mgL^{-1}) Over Depth at Station N18

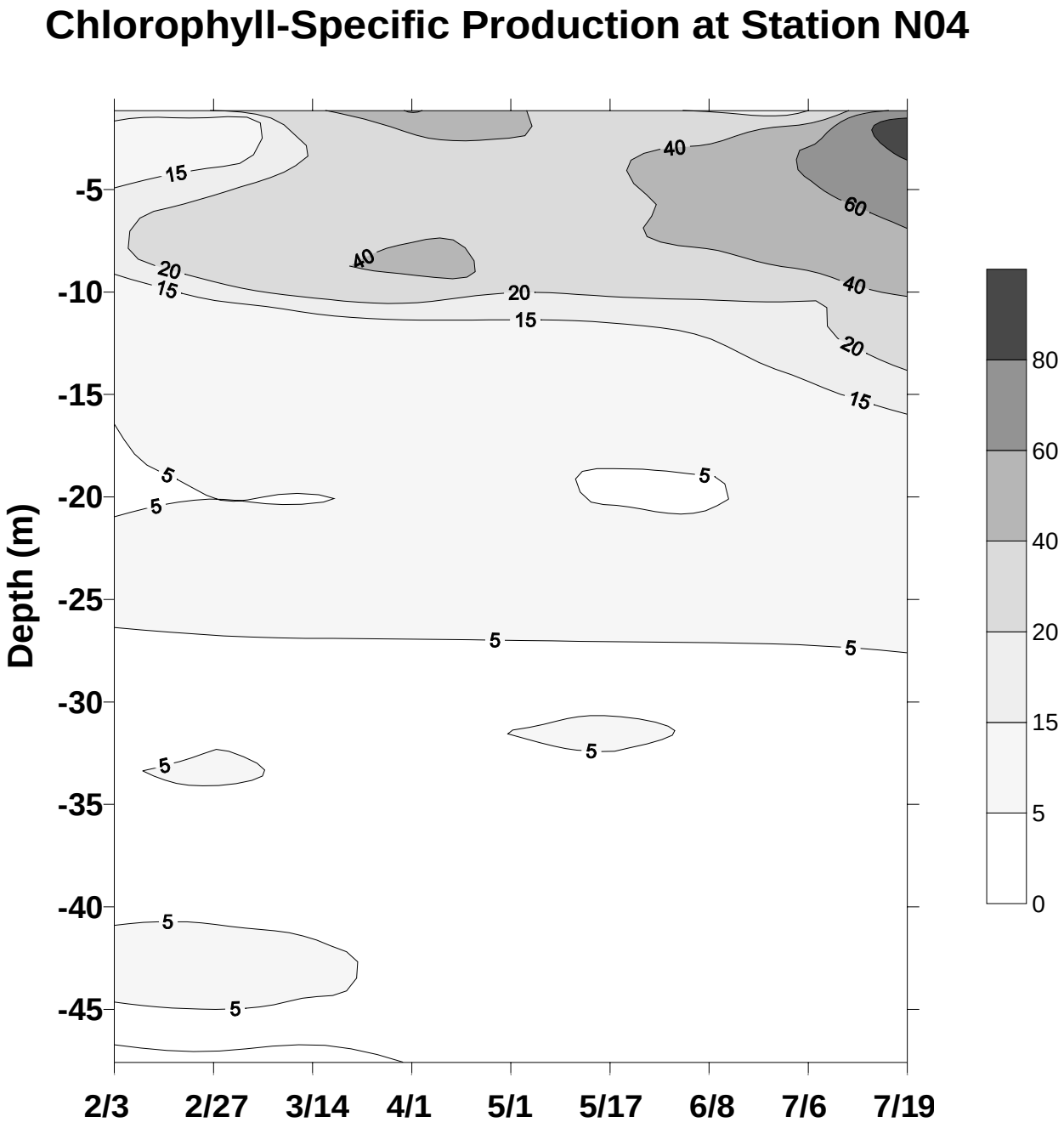


Figure 5-8. Time-Series of Contoured Chlorophyll-Specific Production (mgCmgChl*a*$^{-1}$d^{-1}) Over Depth at Station N04

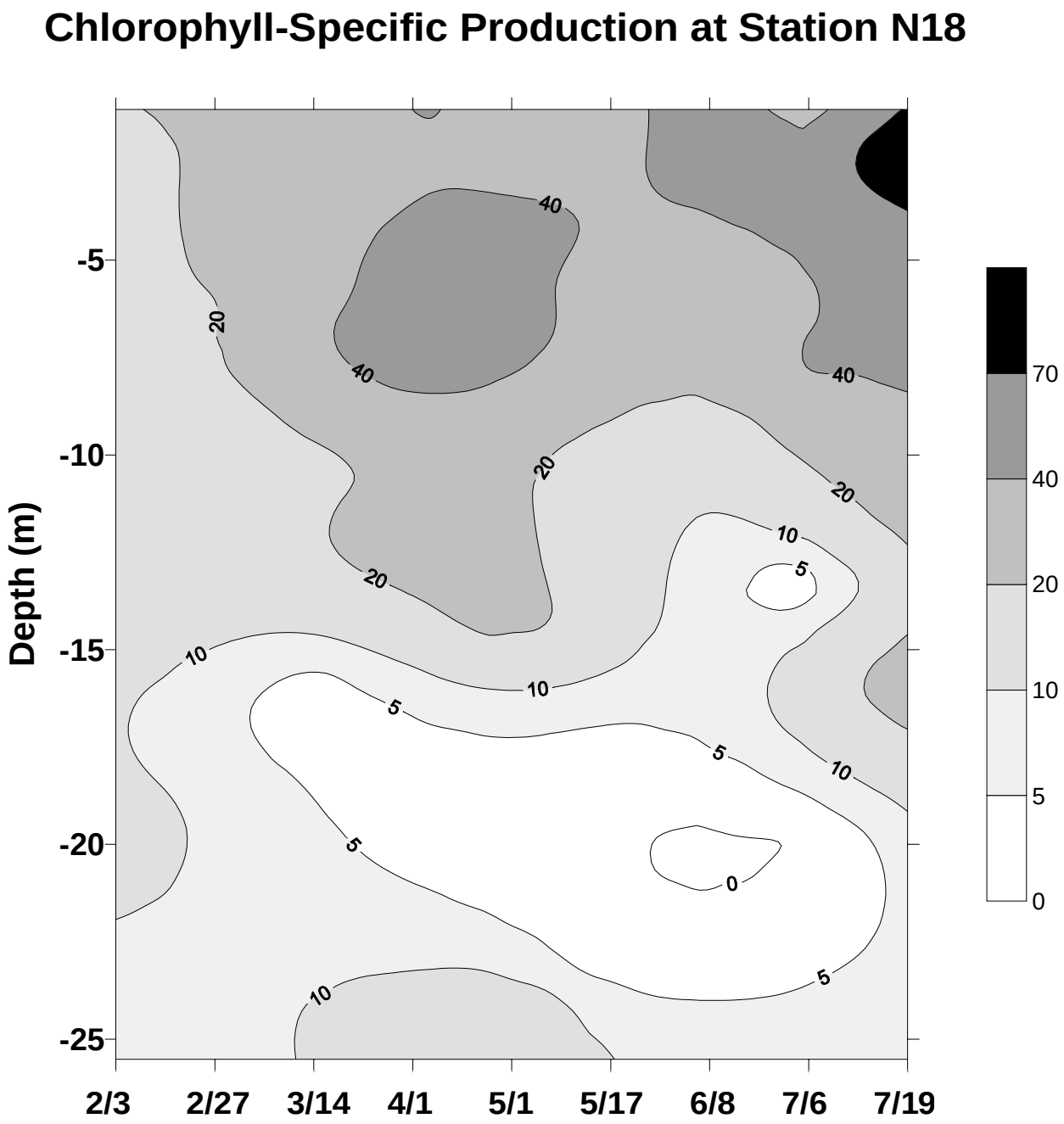


Figure 5-9. Time-Series of Contoured Chlorophyll-Specific Production (mgCmgChl*a*$^{-1}$d^{-1}) Over Depth at Station N18

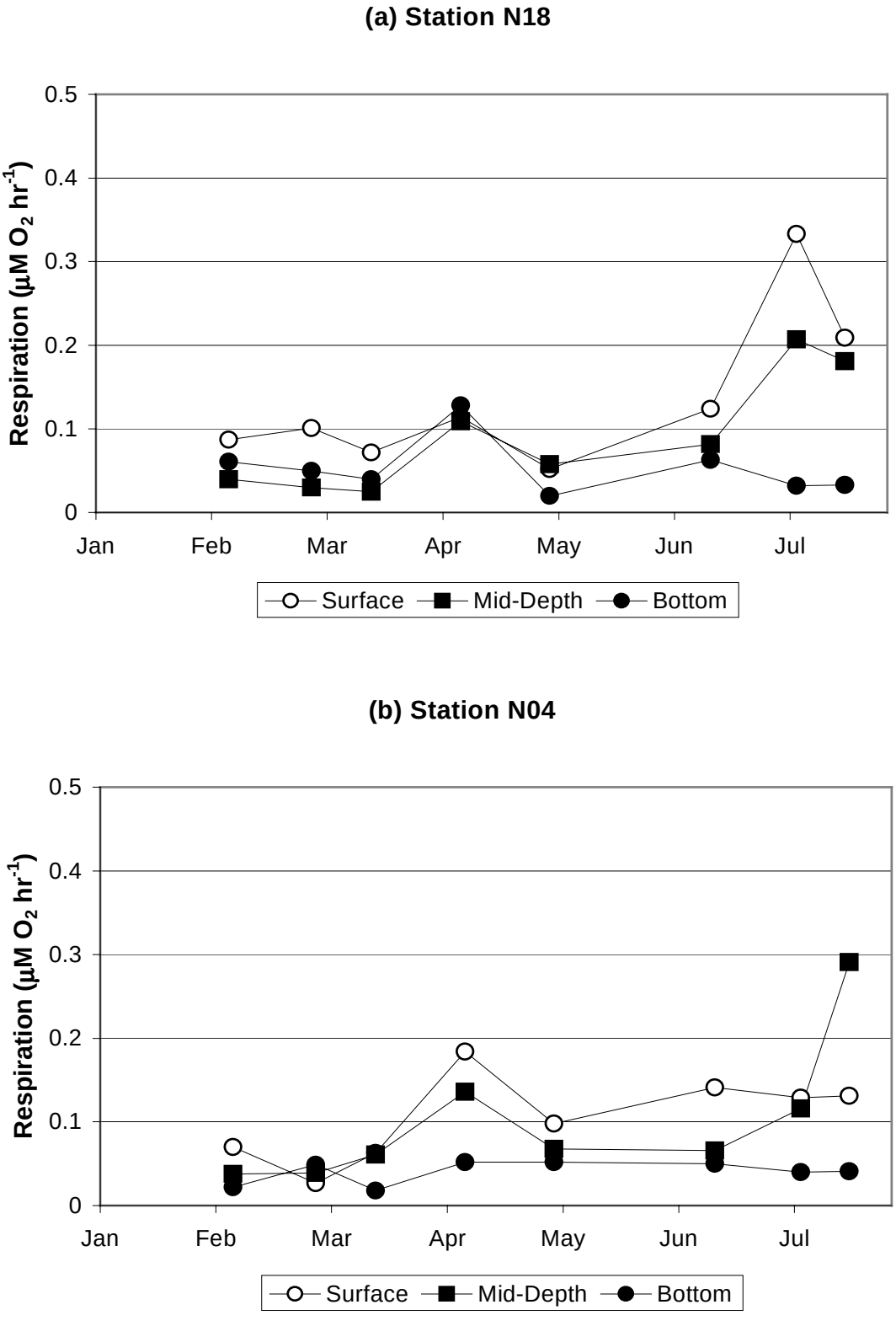


Figure 5-10. Time-Series Plots of Respiration (μMO_2hr^{-1}) Stations N18 and N04

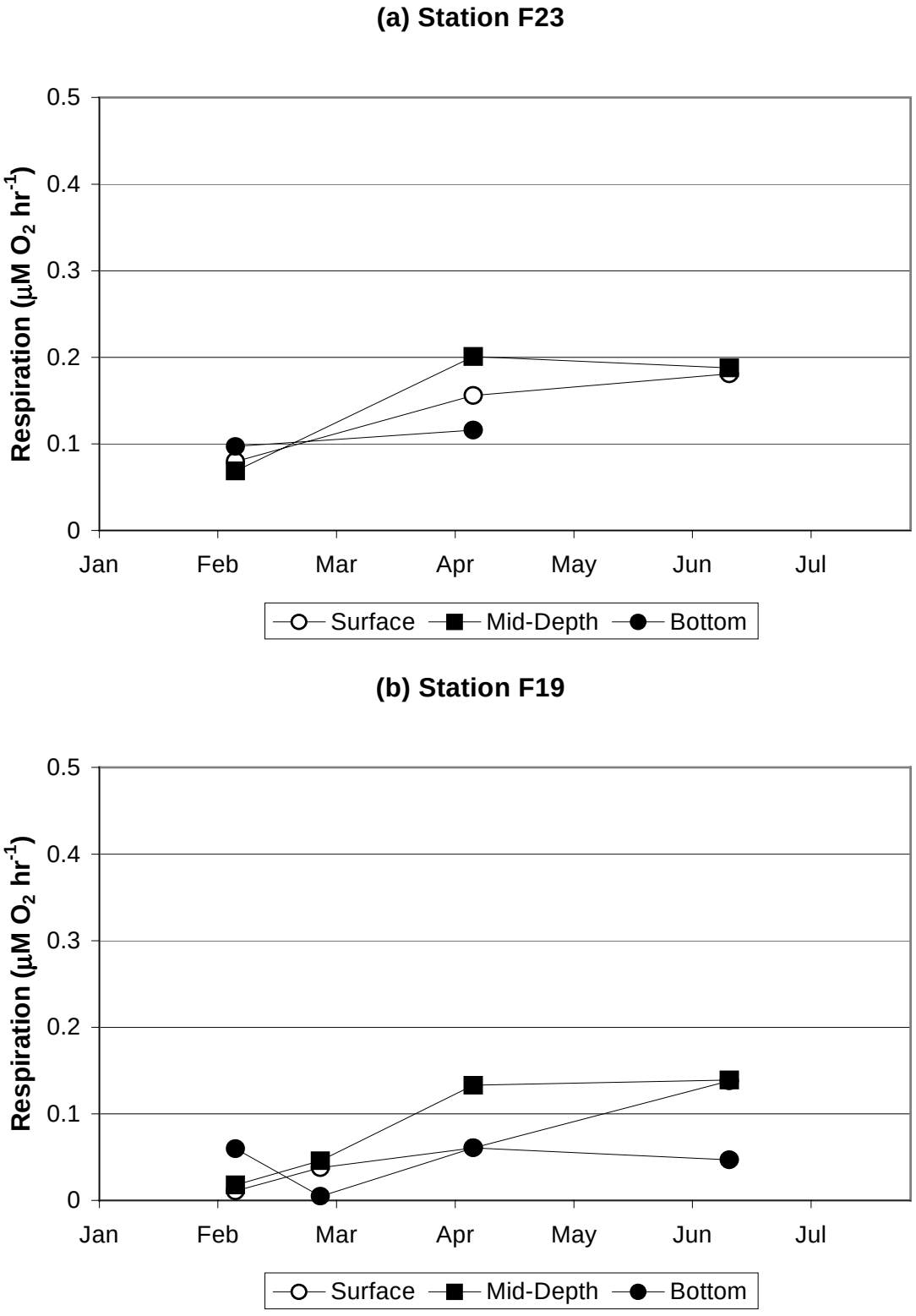
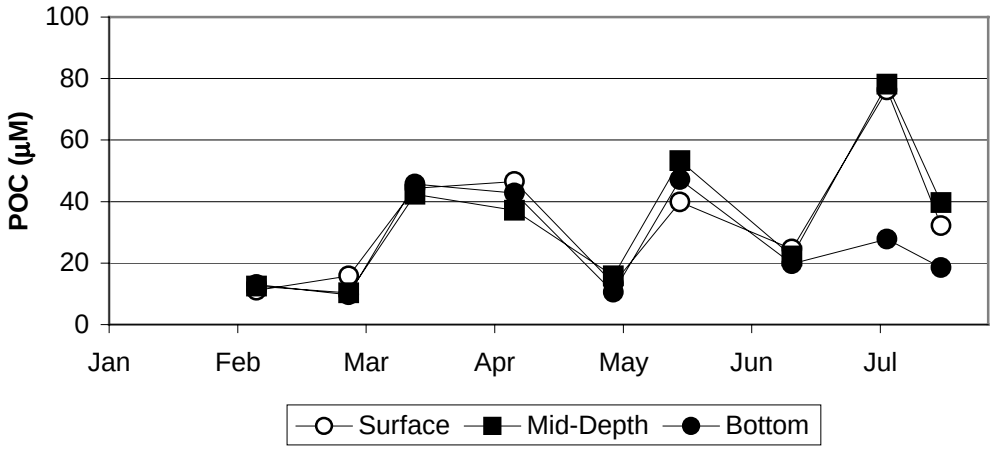
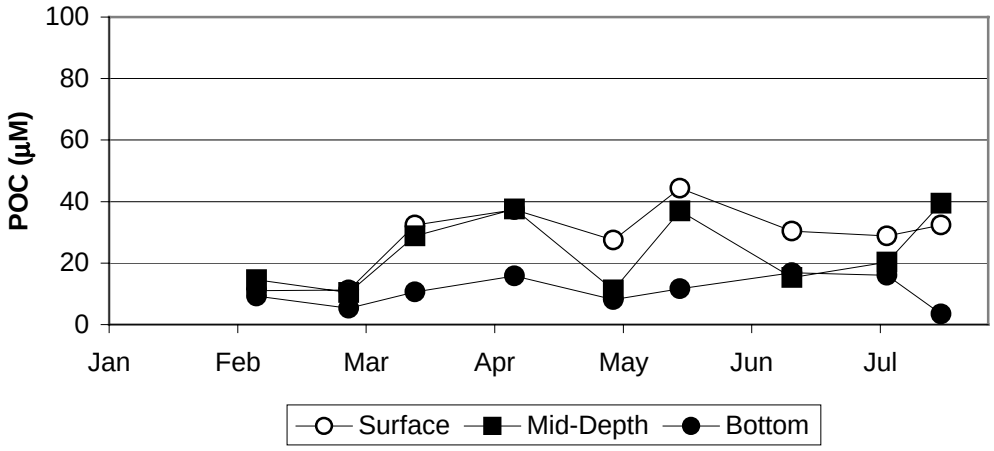


Figure 5-11. Time-Series Plots of Respiration (μMO_2hr^{-1}) Stations F23 and F19

(a) Station N18



(b) Station N04



(c) Station F23

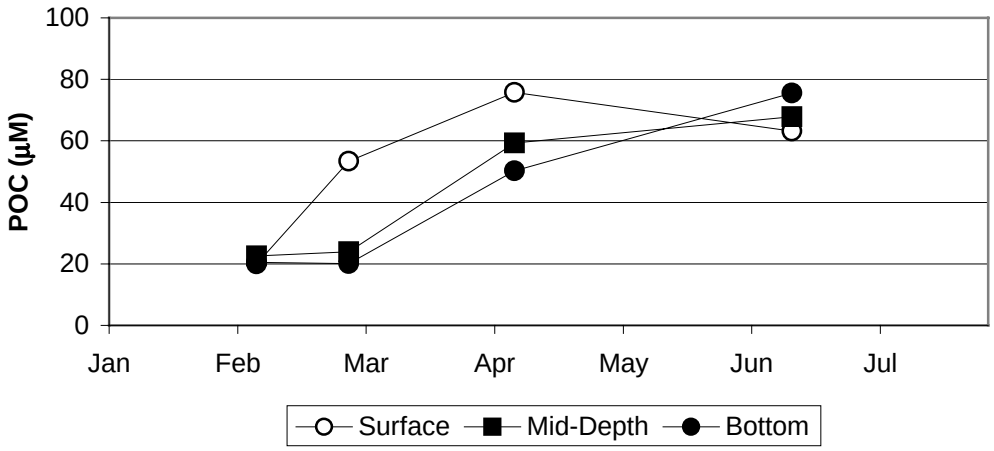


Figure 5-12. Time-Series Plots of POC (µMC) at Stations N18, N04, and F23

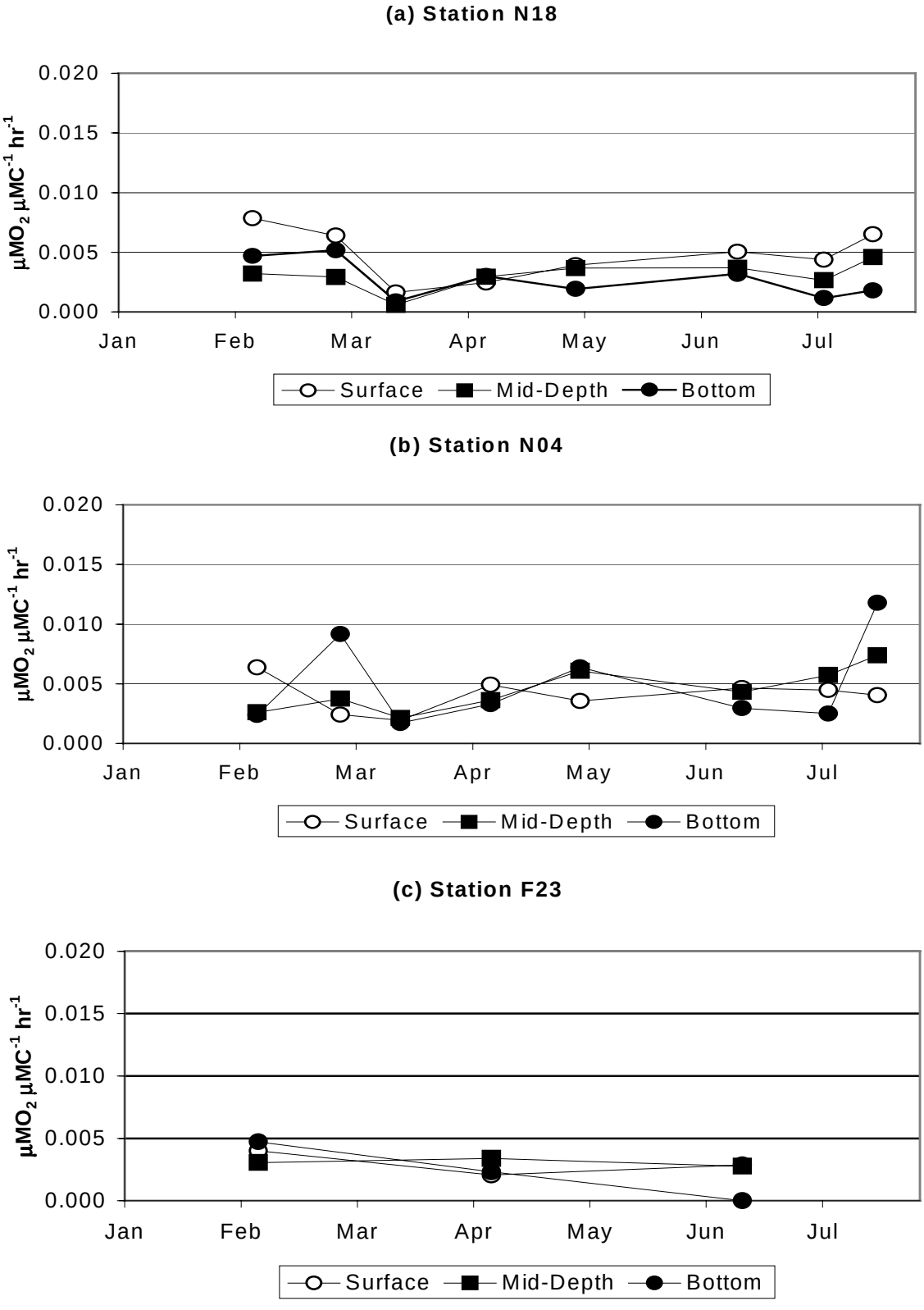


Figure 5-13. Time-Series Plots of Carbon-Specific Respiration ($\mu MO_2 \mu MC^{-1} hr^{-1}$) at Stations N18, N04, and F23

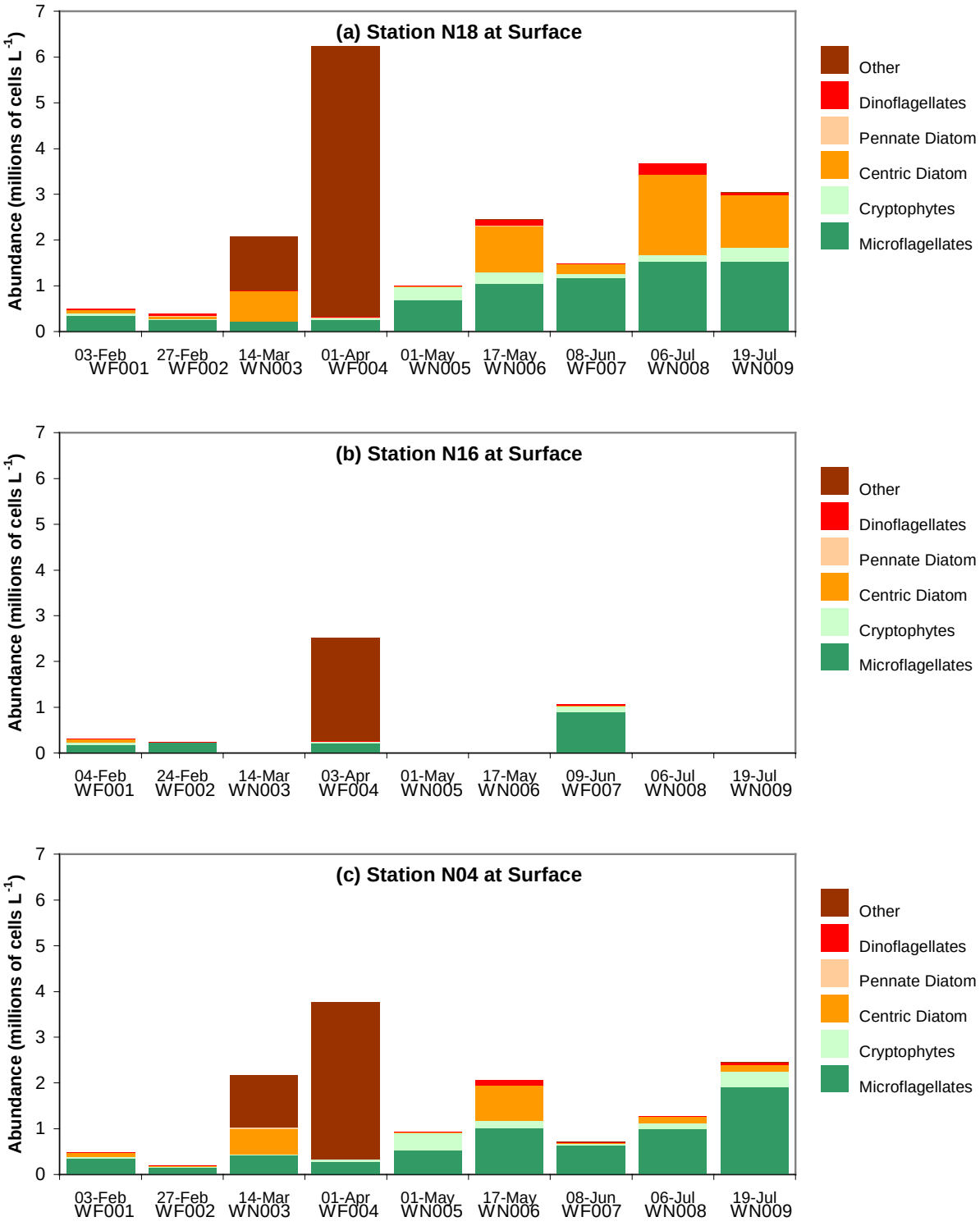


Figure 5-14. Phytoplankton Abundance by Major Taxonomic Group, Nearfield Surface Samples

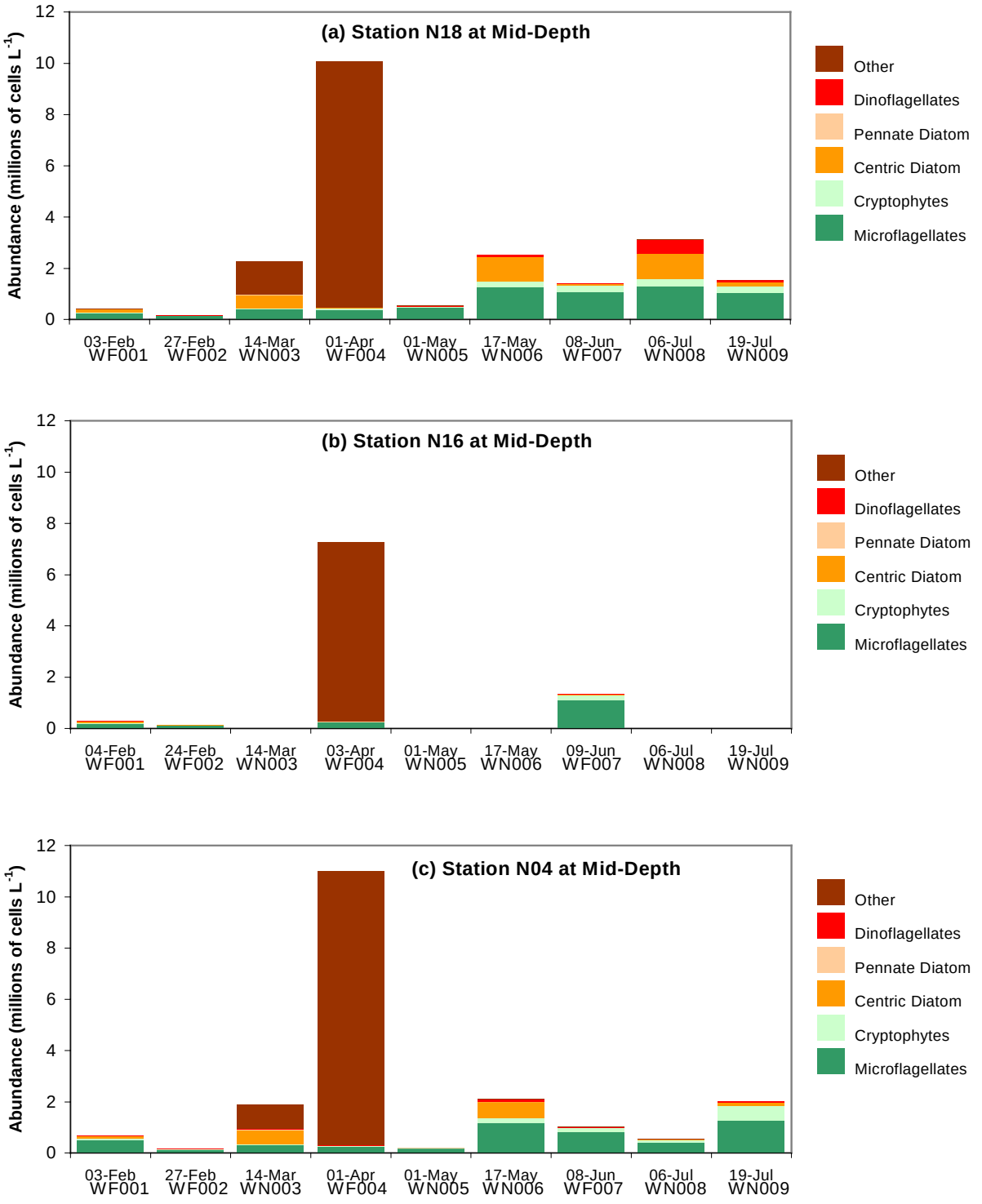


Figure 5-15. Phytoplankton Abundance by Major Taxonomic Group, Nearfield Mid-Depth Samples

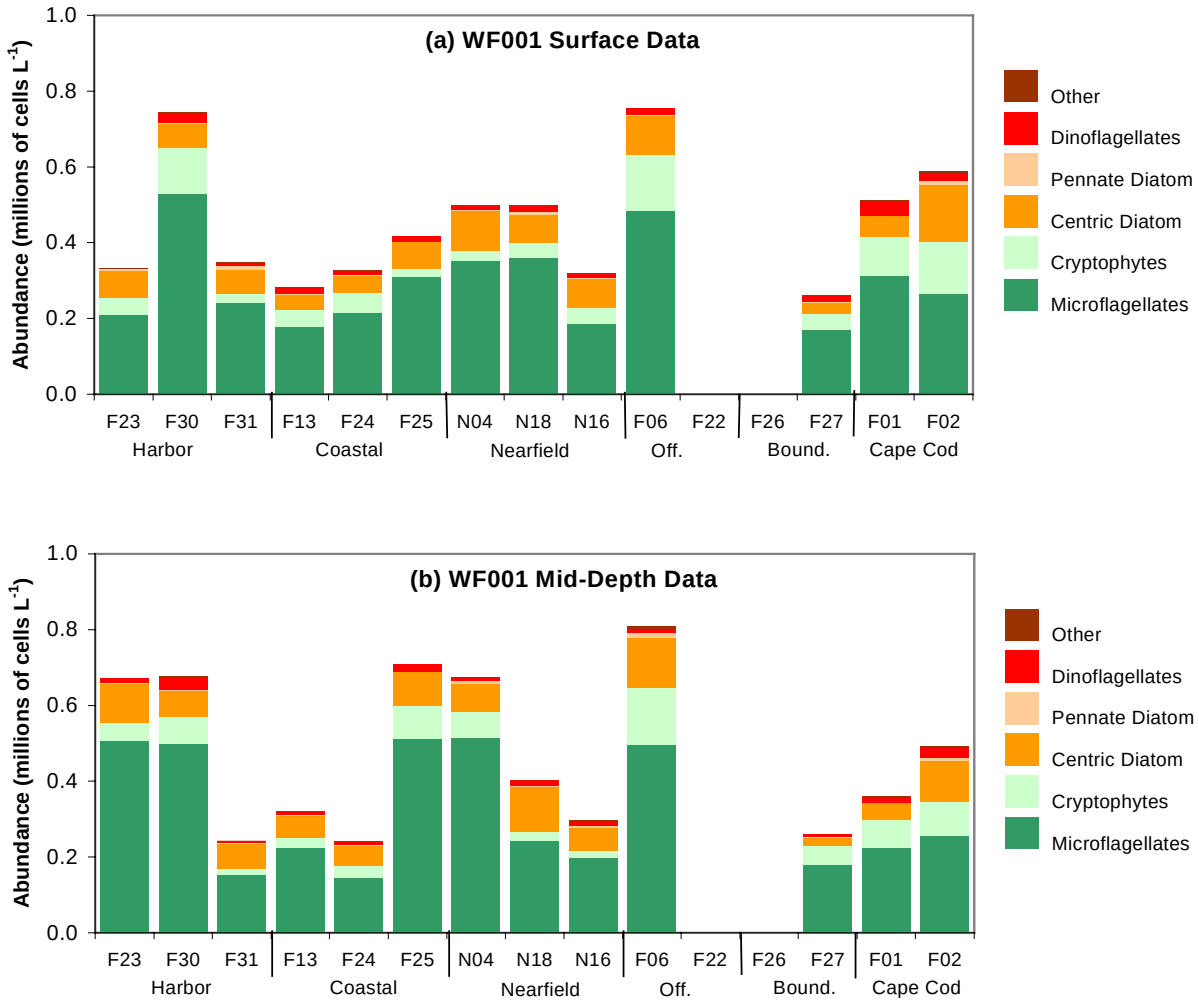


Figure 5-16. Phytoplankton Abundance by Major Taxonomic Group – WF001 Farfield Survey Results (February 2 – 5)

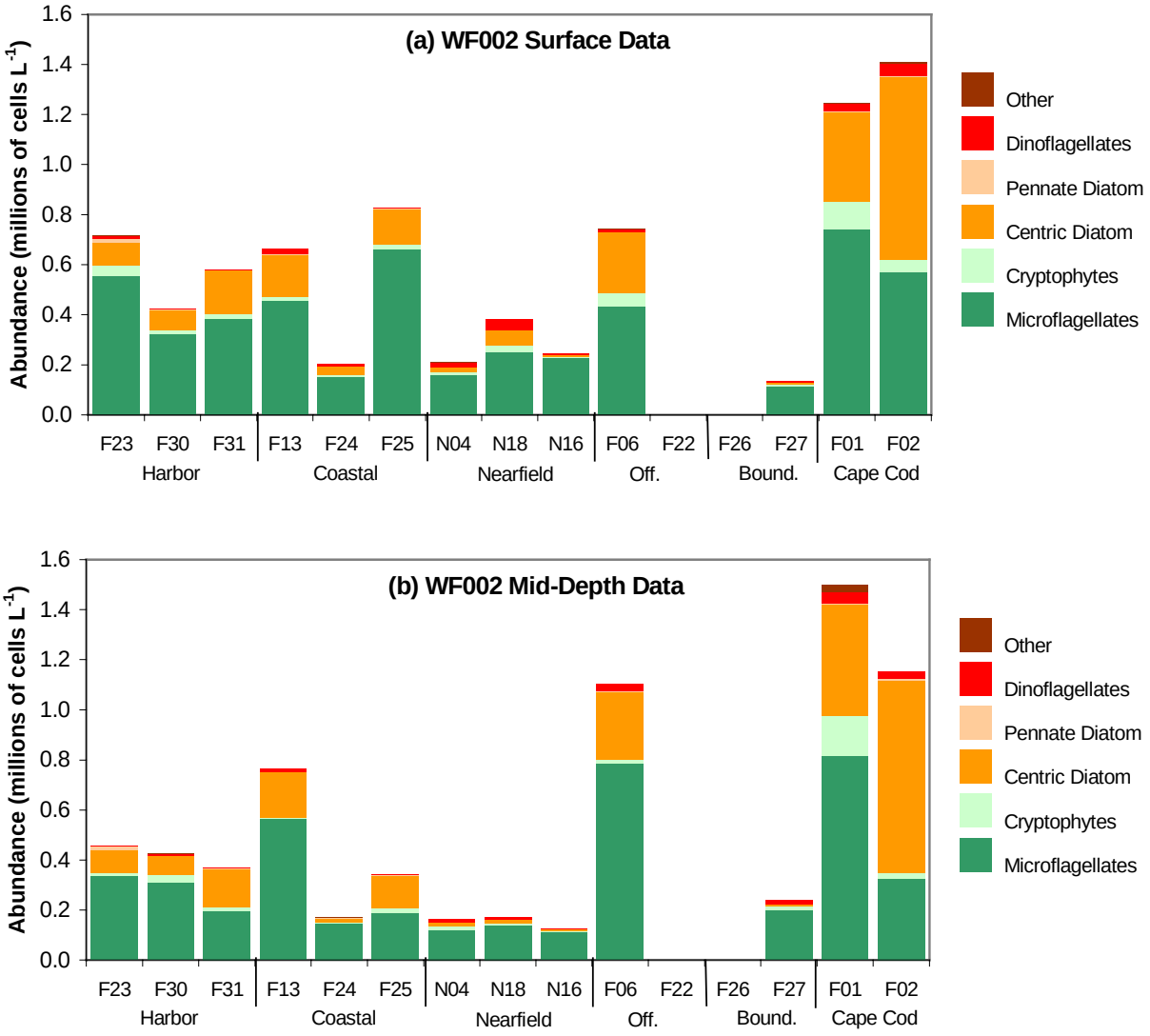


Figure 5-17. Phytoplankton Abundance by Major Taxonomic Group – WF002 Farfield Survey Results (February 23 – 27)

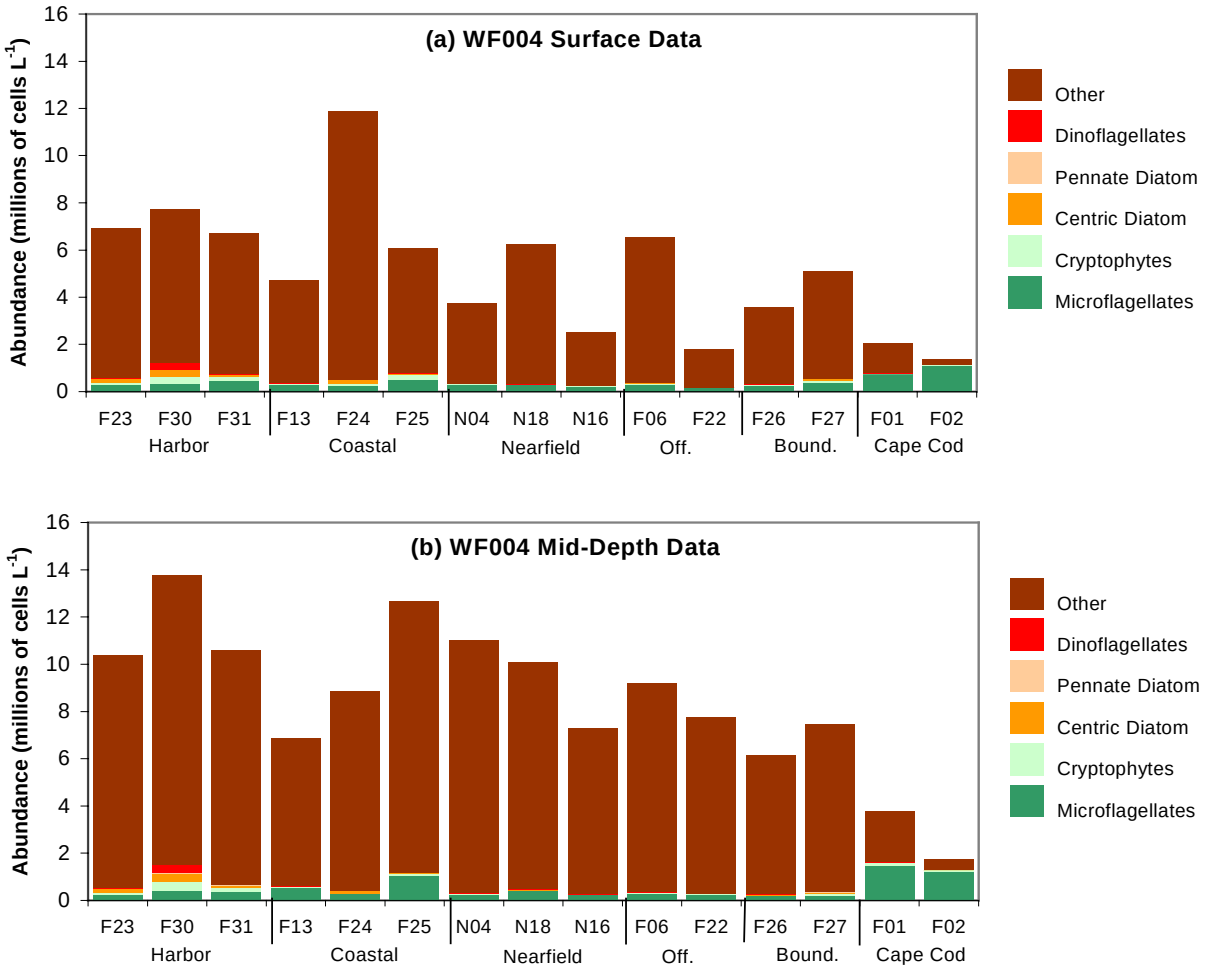


Figure 5-18. Phytoplankton Abundance by Major Taxonomic Group – WF004 Farfield Survey Results (March 30 – April 7)

Figure 5-19. Phytoplankton Abundance by Major Taxonomic Group – WF007 Farfield Survey Results (June 8 – 13)

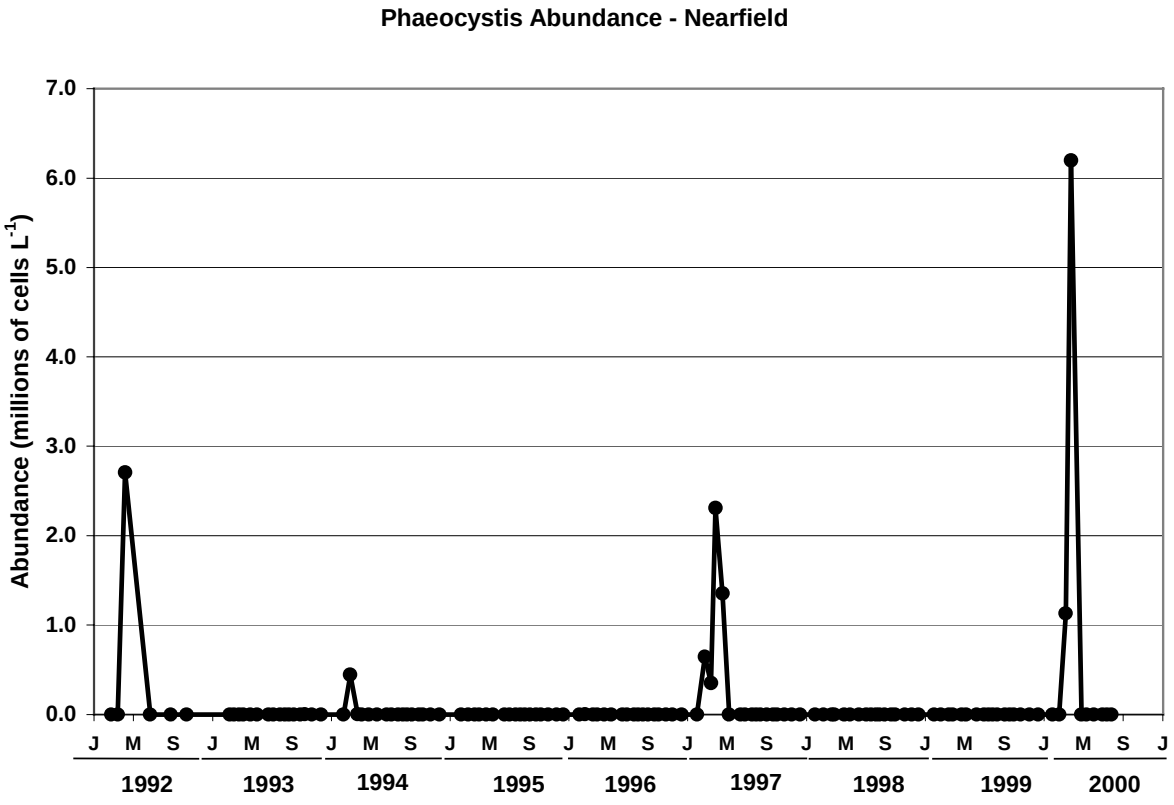


Figure 5-20. Nearfield Average Abundance of *Phaeocystis pouchetii* from 1992 to 2000 (Data Average Includes All Stations and Depths Sampled)

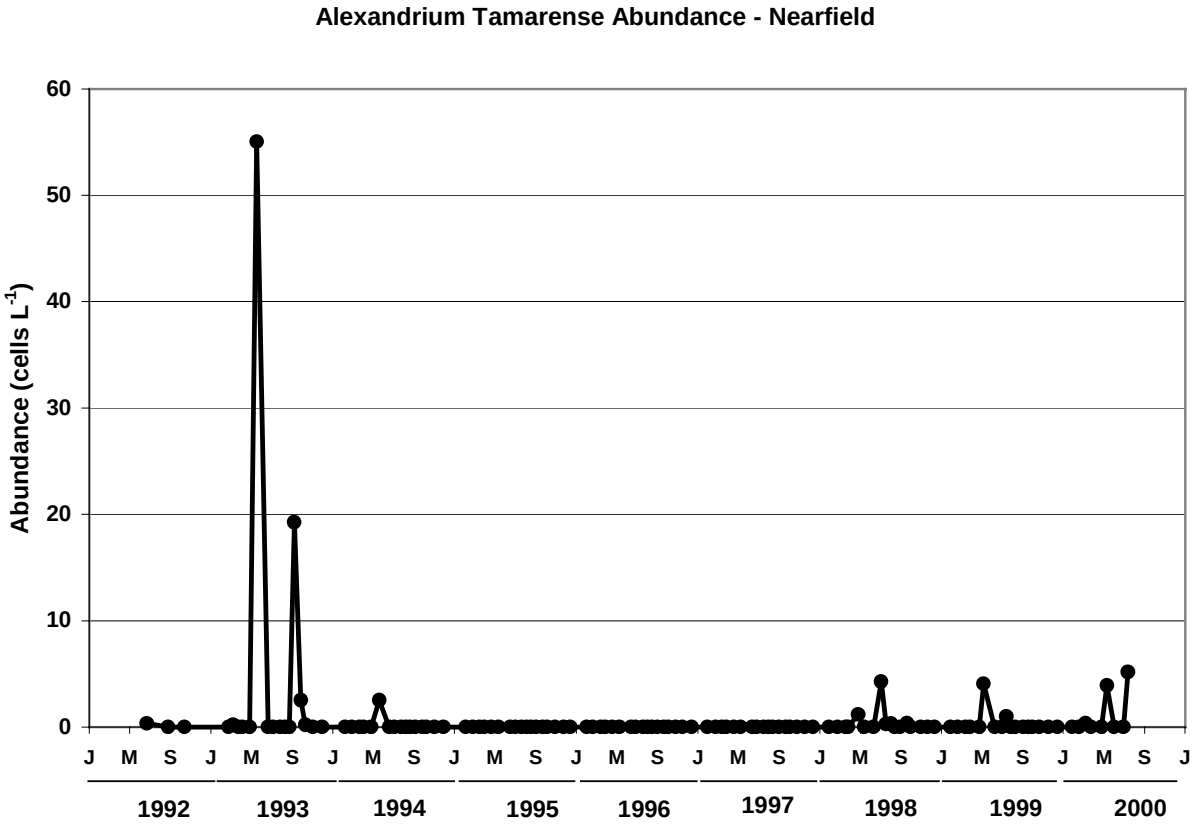


Figure 5-21. Nearfield Average Abundance of *Alexandrium tamarense* from 1992 to 2000 [Data Average Includes All Stations and Depths Sampled (includes counts of *Alexandrium* spp.)]

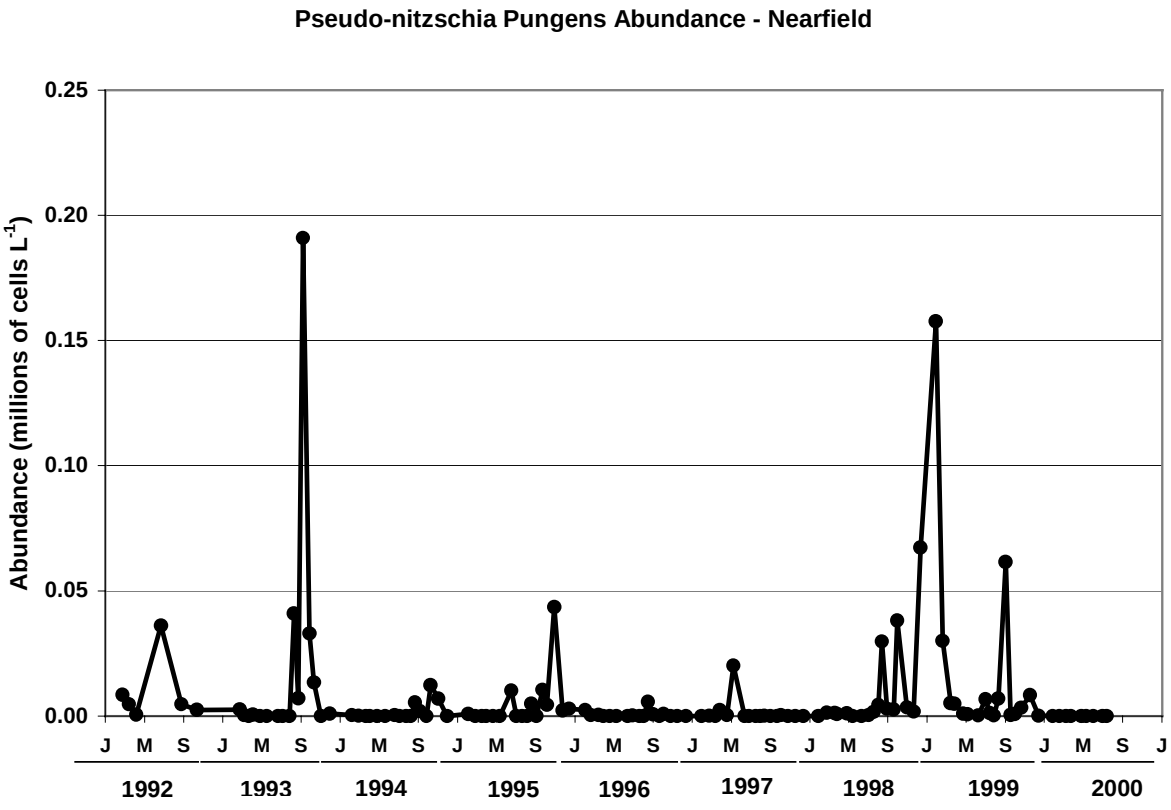


Figure 5-22. Nearfield Average Abundance of *Pseudo-nitzschia pungens* from 1992 to 2000 [Data Average Includes All Stations and Depths Sampled (includes counts of *Pseudo-nitzschia* cf. *Pungens* and *Pseudo-nitzschia* sp.)]

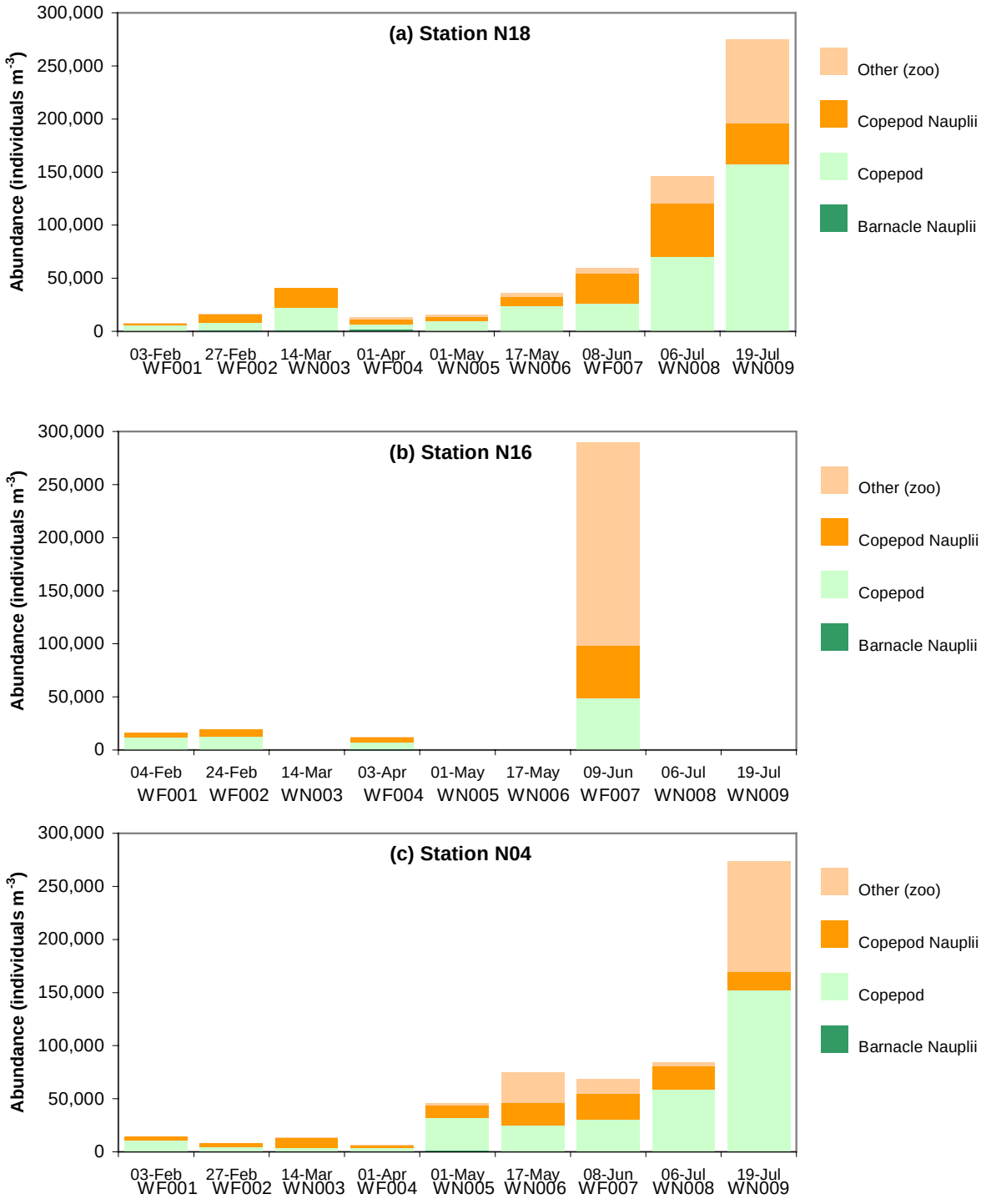


Figure 5-23. Zooplankton Abundance by Major Taxonomic Group, Nearfield Samples

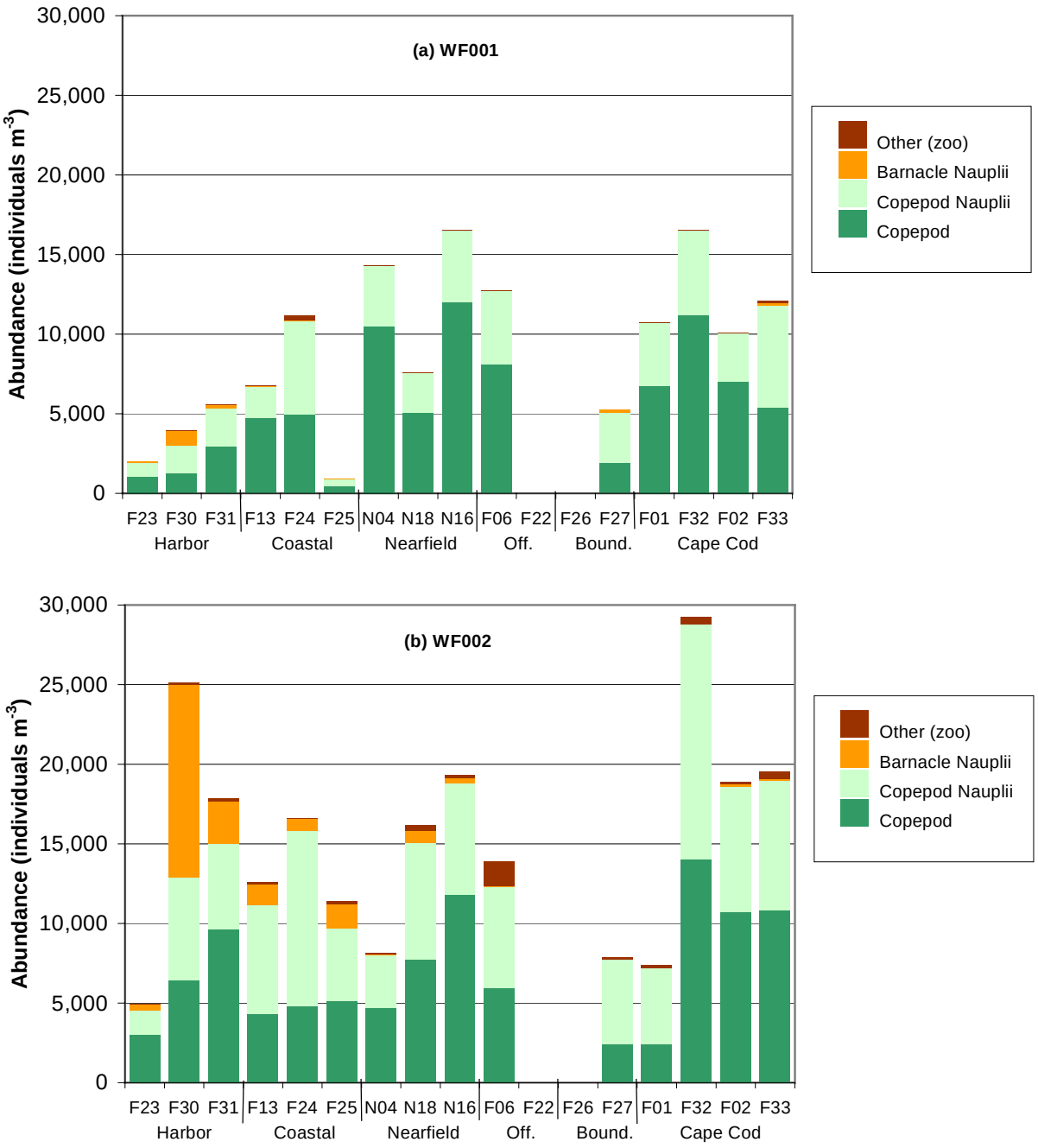


Figure 5-24. Zooplankton Abundance by Major Taxonomic Group – A) WF001 Farfield Survey Results (February 2 – 5) and B) WF002 Farfield Survey Results (February 23 – 27)

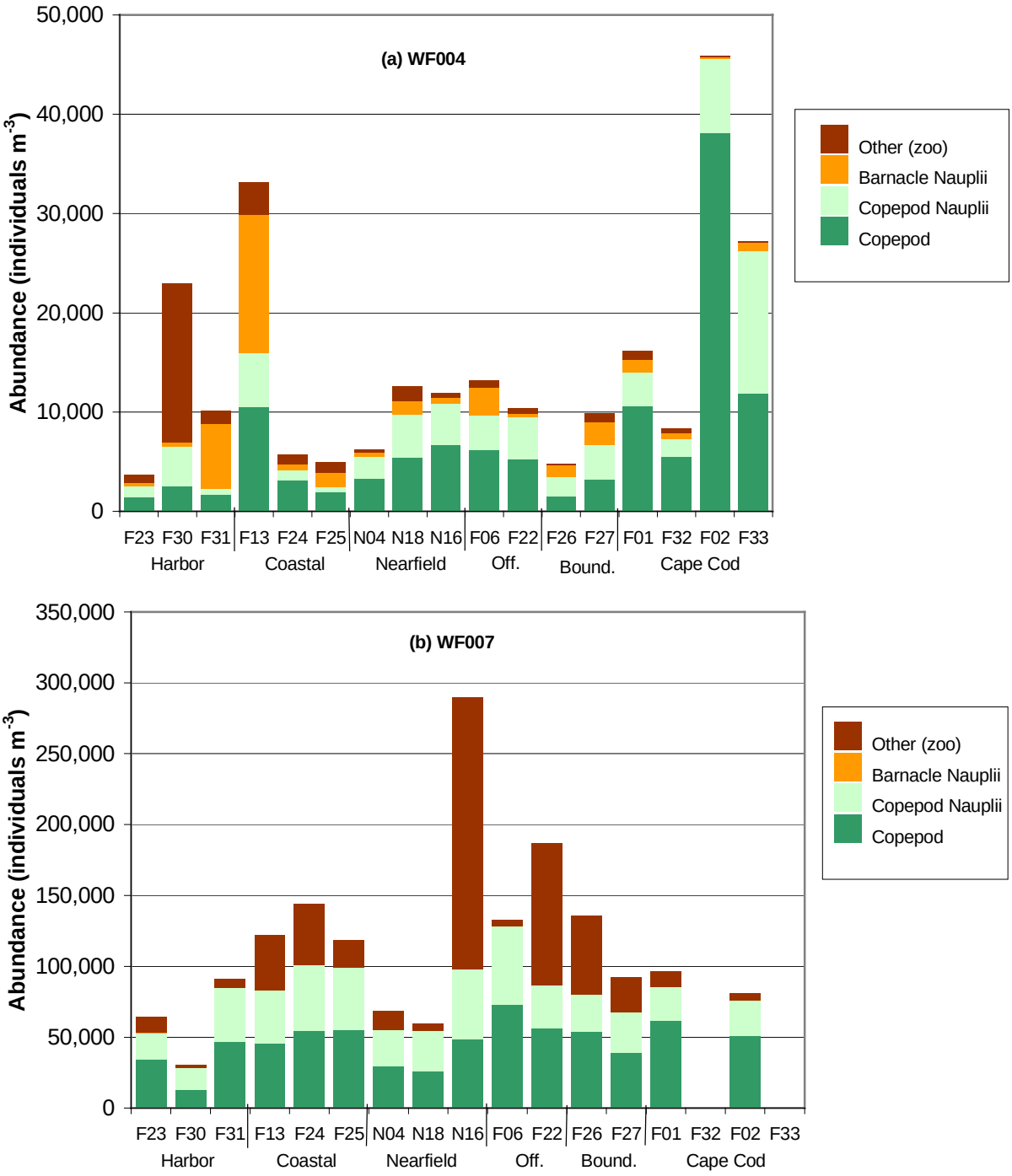


Figure 5-25. Zooplankton Abundance by Major Taxonomic Group – A) WF004 Farfield Survey Results (March 30 – April 7) and B) WF007 Farfield Survey Results (June 8 – 13)

6.0 SUMMARY OF MAJOR WATER COLUMN EVENTS

The winter to spring transition in Massachusetts and Cape Cod Bays is characterized by a typical series of physical, biological, and chemical events: seasonal stratification, the winter/spring phytoplankton bloom, and nutrient depletion. This was generally the case in 2000 although inclement weather resulted in a delay in the establishment of stratified conditions. The winter/spring bloom in 2000 was characterized by unprecedented abundances of *Phaeocystis pouchetii* and very high chlorophyll concentrations. Surface waters across much of the region were depleted in nutrients from April through July following the bloom. This section presents a summary of these events and the integrated physical, biological, and chemical trends discussed in previous sections.

During the first three surveys of 2000 (February through March), the water column was well mixed and relatively high concentrations of nutrients were measured. Nearfield surface nutrient concentrations decreased from February to March coincident with increasing chlorophyll concentrations, elevated primary production rates, and the initiation of the *Phaeocystis* bloom. By late February, there was an increase in phytoplankton abundance in Cape Cod Bay and southern Massachusetts Bay with a mixed assemblage dominated by microflagellates and centric diatoms. By March, phytoplankton abundance had begun to increase in the nearfield and the assemblage was dominated by centric diatoms and *Phaeocystis pouchetii*, which was the winter/spring bloom species for 2000.

The onset of stratification was observed during the April survey in Boston Harbor and at the deep boundary stations. The development of stratification at these stations was primarily driven by a decrease in surface salinity, as surface and bottom water temperatures remained relatively unchanged. By June, surface water temperatures had increased by ~7°C throughout the bays and a strong density gradient was observed at the offshore and boundary stations. Due to storm events and associated mixing, stratification was still weak at the shallower coastal, Cape Cod Bay, and Boston Harbor stations. Boston Harbor usually remains well mixed due to tidal flushing. In the nearfield, the water column had begun to stratify in early May at the deeper eastern nearfield stations. The storm events in June remixed the water column and contributed to the relatively weak stratification that was observed. By July a strong density gradient and stratified conditions had become established in the nearfield.

The nutrient data for February to July 2000 generally followed the "typical" progress of seasonal events in the Massachusetts and Cape Cod Bays. Maximum nutrient concentrations were observed in early February when the water column was well mixed and biological uptake of nutrients was limited. The winter/spring *Phaeocystis* bloom reduced nutrient concentrations in the surface waters from March to April. NO_3 and PO_4 concentrations in the surface waters were depleted throughout much of the region. In July, seasonal stratification led to persistent nutrient depleted conditions in the surface waters and ultimately to an increase in nutrient concentrations in bottom waters due to increased rates of remineralization of organic matter. The typical harbor signal of elevated nutrient concentrations (especially ammonium) was observed throughout this time period. During the *Phaeocystis* bloom, however, even nutrient concentrations in Boston Harbor decreased substantially.

The most significant event during the February to July 2000 time period was the system-wide bloom of *Phaeocystis pouchetii* in March/April. Phytoplankton abundance reached unprecedented levels in April with *Phaeocystis* abundance levels approaching 14 million cells L^{-1}. In correlation with the *Phaeocystis* bloom, the mean chlorophyll concentration for the nearfield for winter/spring was higher than any previous winter/spring mean obtained during the baseline monitoring period and exceeded

the provisional chlorophyll threshold value that had been calculated as two times the baseline mean for 1992 to 1998. The elevated chlorophyll concentrations and phytoplankton abundance were concomitant with high production rates. At station N18, production reached a maximum value in March (4269 $mgCm^{-2}$ d^{-1}) and remained elevated in April (2780 $mgCm^{-2}d^{-1}$). The peak at station N04 occurred in April (3118 $mgCm^{-2}d^{-1}$). Areal production in 2000 followed patterns typically observed in prior years – a winter-spring bloom at nearfield stations with production rates of 1000 to 4000 mg C m^{-2} d^{-1} that typically last 2-3 months. In Boston Harbor, the typical pattern is for production rates to increase from winter through summer rather than the distinct winter-spring peaks observed in the nearfield. In 2000, however, this was not the case as peak production at station F23 occurred in April (4378 C m^{-2} d^{-1}). The earlier occurrence of peak production values in the harbor was likely due to the system-wide *Phaeocystis* bloom.

Dissolved oxygen concentrations in 2000 were within the range of values observed during previous years and followed the typical trends. In February, DO concentrations were high and consistent across the region. By April, vertical gradients in DO concentration were observed due to the high rates of biological production. Between the April and June surveys, there was a sharp decline in bottom water DO throughout the bays (1-3 mgL^{-1}). The trend of declining bottom water DO concentrations following the establishment of stratification and the cessation of the winter/spring bloom is typical for the bays. The decline observed in 2000 was less than that seen during 1999 and may be an indication that bottom water DO concentrations during the fall of 2000 may not achieve the very low levels seen in the fall of 1999.

Two of the major factors affecting bottom water DO concentrations are physical mixing or reventilation of bottom waters and biological respiration/utilization of organic material. Storm events in April and June likely caused a delay in the onset of seasonal stratification in the region in 2000. In June, it appears that bottom waters were reventilated as oxygen-rich surface waters were being mixed down to depth as a result of the storm events. Respiration rates in 2000 were relatively low compared to 1999, which also had a significant winter/spring bloom. The respiration rates measured in 2000 were less than half of the peak rates measured in 1999. The relatively low respiration rates observed during the winter/spring of 2000 versus 1999 may be related to the type of phytoplankton that bloomed in 2000 (*Phaeocystis*) versus 1999 (mixed diatom assemblage). The effect of these physical and biological factors resulted in somewhat higher bottom water DO concentrations in 2000 (~0.5 mgL^{-1}) in comparison to values measured in 1999. This topic will be evaluated in more detail in the 2000 Nutrient Issues Review.

The bloom of *Phaeocystis pouchetii* was the only bloom of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during February – July, 2000. The dinoflagellate *Alexandrium tamarense* and diatoms of *Pseudo-nitzschia pungens* and *Pseudo-nitzschia* spp. were recorded, but abundance levels were extremely low.

Zooplankton abundance generally increased from February through July. Nearfield counts of nearly 300 x 10^3 animals m^{-3} in June were among the highest for the entire 1992-2000 baseline period. The high June abundance observed in the nearfield was due to a very high number of bivalve veligers at station N16. Zooplankton abundance at station N16 was 5 to 6 times higher than at the other nearfield stations N04 and N18, which had been sampled on the day prior to sampling at station N16. The June nearfield zooplankton data is indicative of the biological (spawning) and physical (tides and currents) variability associated with meroplankton abundances and distribution in Massachusetts Bay. In general, zooplankton assemblages during the first half of 2000 were comprised of typical taxa for the region: *Oithona similis, Pseudocalanus* spp., *Calanus finmarchicus,* and *Centropages* spp..

Levels of *Acartia* spp. rebounded from the unusually low values of the previous year, which were possibly due to drought, to more typical levels during the rainy spring and early summer in 2000.

A number of topics were called out in this report that will be discussed in greater detail in the 2000 annual water column report including the following:

- Year-to-year variability in winter/spring chlorophyll concentrations. The last two years of monitoring (1999-2000) have seen winter/spring nearfield mean chlorophyll concentrations that are substantially higher than levels from 1992 to 1998.
- Effect of physical and biological factors on bottom water DO concentrations in Massachusetts Bay. This will be evaluated in detail in the 2000 Nutrient Issues Review and results will be included in the annual report to describe trends during this monitoring year.
- Continued observation of elevated ammonium concentrations and the effect on biological processes in the nearfield and near-harbor coastal waters.
- The apparently cyclical nature of *Phaeocystis* blooms in Massachusetts Bay and the regional expression of these blooms (*i.e.* Gulf of Maine).

7.0 REFERENCES

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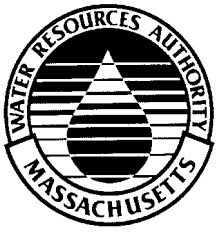

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